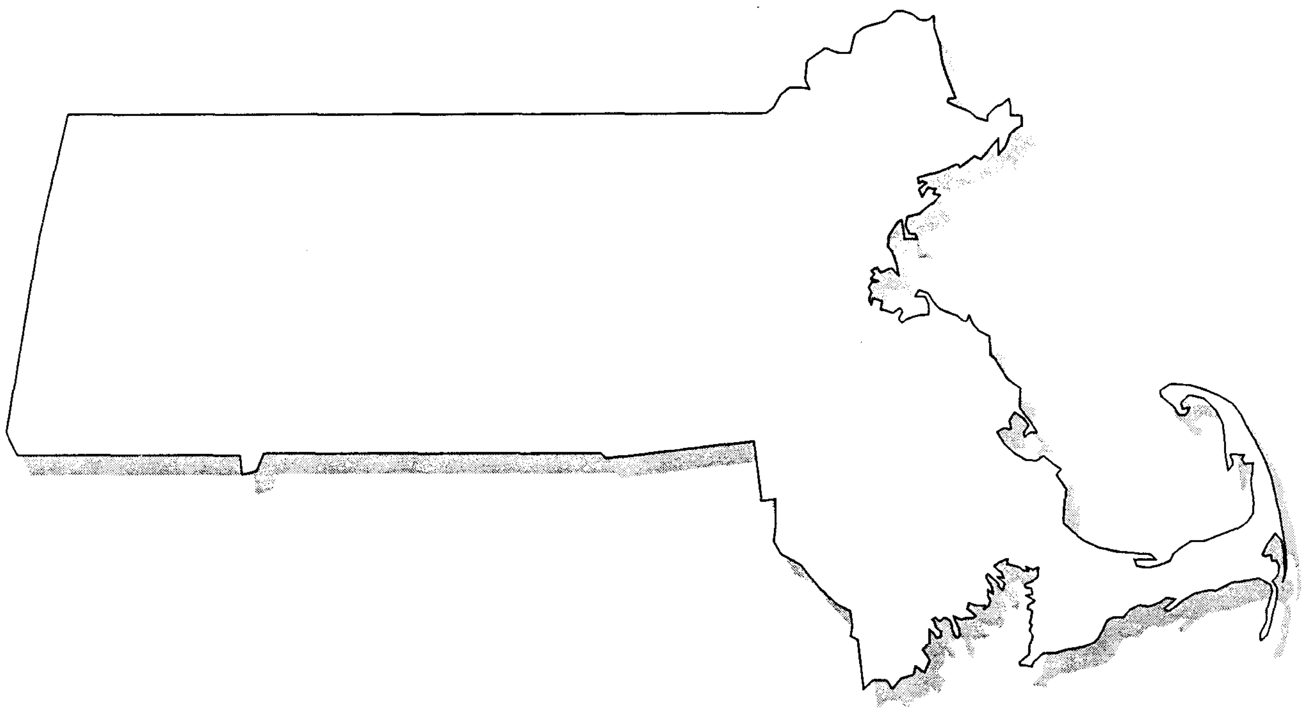
Section 206
Flood Plain Management Services

FLOOD WARNING AND PREPAREDNESS IN MASSACHUSETTS



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Executive Summary

The Commonwealth of Massachusetts, Executive Office of Environmental Affairs (EOEA), Department of Environmental Management (DEM), requested the Corps of Engineers assistance to investigate the role of early flood warning and response to reduce flood losses throughout the state. This report was completed under the Corps' Flood Plain Management Services (FPMS) authority contained in Section 206 of the 1960 Flood Control Act (Public Law 86-645). The purposes of this report are to describe the need for flood warning and response in the Commonwealth and to describe ways to improve flood warning and response within the State.

The National Weather Service (NWS) is the Federal agency responsible for the formulation and issuance of flood forecasts, watches and warnings in the United States. Forecasts by the NWS vary in their specificity and timeliness, depending primarily upon the length of time for a river or stream to crest. Specific forecasts generally are prepared only for rivers with long crest times. The NWS prepares three types of forecast; 1) river and flood forecasts for major rivers, 2) headwater forecasts for headwater river basins, and 3) flash flood watches and warnings for small streams. The NWS also provides limited assistance to communities in implementing local self-help flood warning systems and statewide flood warning systems. The NWS' Northeast River Forecast Center (NERFC) in Bloomfield, Connecticut, is charged with the responsibility of forecasting the flows of the major rivers throughout New England. The NERFC issues river stage forecasts for seventeen locations in Massachusetts with drainage areas ranging in size from 35 to 9,587 square miles.

This report examines the existing flood warning and response capabilities provided to the Commonwealth of Massachusetts by the NWS and discusses the role of ALERT and the NWS's IFLOWS flood warning and response systems in improving the current level of warning coverage. The study identifies the locations where the NWS provides specific flood forecasts within the Commonwealth and discusses the more generalized warnings and watches prepared for the remaining areas. The study determined that the level of warning provided by the NWS meets the public safety concerns for the major flood prone areas of the Commonwealth. Furthermore, the report did not identify any gaps in precipitation or stream flow data which impacts on the preparation or the accuracy of the forecasts prepared by the NWS.

The current NWS coverage combined with the existing communication system established by the Massachusetts Emergency Management Agency (MEMA) would indicate that the implementation of a statewide system such as IFLOWS is not necessary. However, this flood warning assessment report does identify numerous locations within the Commonwealth which could benefit from the implementation of additional warning capabilities. These locations are typically concentrated areas of development along rivers or streams with small drainage areas. These locations receive some public safety benefit from the warnings and watches issued by the NWS for the large precipitation events, but can still experience flooding from more concentrated storms with little advanced warning. The advanced warning provided by the normal NWS procedures allows for little reaction time beyond the evacuation of the flood prone areas. These locations appear to be promising candidates for local flood warning systems to both increase the reaction time available to evacuate the flood plains and to incorporate flood damage reduction measures to reduce flood losses. It should be stressed, however, that flood warning in itself is not a complete solution to flooding, only a means of reducing the potential risk to people and property.

If the Commonwealth of Massachusetts or the communities in the locations identified in this report wish to pursue the implementation of ALERT systems, several important issues must be stressed. The first is the determination of the appropriate type of flood warning system. If the principal objective of the system is the protection and safe evacuation of flood prone areas, then a simple alarm type system may be sufficient. Some limited flood damage reduction may be possible with this type of system. These systems are generally inexpensive and do not require extensive training to operate after their initial implementation and calibration. The NWS and other Federal and state agencies may be able to provide technical support to lay out the system and to set the proper rainfall or stream flow threshold levels. If the goal of the system is a more complete reduction in flood damages, then a more comprehensive system with internal flood forecasting capabilities may be required.

The second important issue which should be addressed is the preparation of a comprehensive emergency response plan. The emergency response plan should provide a link between the public affected by a flooding event and the flood warning system. The plan should be prepared in conjunction with the implementation of the flood warning system and should completely address the procedures, responsibilities, and actions of the community in disseminating the warning information to the affected community and identifying the response measures which are the responsibility of the local government. The preparation of a preparedness plan is appropriately a local responsibility and should be considered a significant undertaking. Programs are available from Federal agencies such as the NWS and the Corps of Engineers to assist in the preparation and content of the plans.

The final issue associated with flood warning systems is the long term support and maintenance of the systems. A mechanism needs to be implemented at a state or regional level to protect the initial investment in the system features and maintain an educated user community dedicated to the long term success of the systems. This type of commitment may be difficult to expect from an individual community. A mechanism similar to the ASERT/ALERT program adopted by the State of Connecticut would be a good model to follow.

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I. INTRODUCTION

STUDY PURPOSE

The Commonwealth of Massachusetts, Executive Office of Environmental Affairs (EOEA), Department of Environmental Management (DEM), requested the Corps of Engineers assistance to investigate the role of early flood warning and response to reduce flood losses throughout the state. The purposes of this report are to describe the need for flood warning and response in the Commonwealth and to describe the ways to improve flood warning and response within the State. In accomplishment of these purposes, the report does the following:

1. Describes the components of flood warning and response systems;

2. Describes the role of flood warning and response in the reduction of deaths and injuries and in reducing flood damages;

3. Describes existing resources/capabilities within the State to provide warnings;

4. Discusses the advantages and disadvantages of a statewide versus a local approach in meeting flood warning needs;

5. Performs a preliminary economic analysis to identify potential locations where early flood warning and response improvements could be beneficial.

6. Suggests a role for the State government in improving the Massachusetts early flood warning response capabilities.

STUDY AUTHORITY

Authority for U.S. Army Corps of Engineers participation in this effort is sanctioned by Section 206 of the 1960 Flood Control Act (Public Law 86-645) which states:

> "...The Secretary of the Army, through the Chief of Engineers, Department of the Army, is hereby authorized to compile and disseminate information on floods and flood damages, including identification of areas subject to inundation by floods of various magnitudes and frequencies, and general criteria for guidance in the use of flood plain areas and to provide engineering advice to local interests for their use in planning to ameliorate the flood hazard..."

ACKNOWLEDGMENTS

This study was conducted by the New England Division, Army Corps of Engineers, under the general supervision of Mr. Joseph L. Ignazio, Chief, Planning Directorate, Mr. John Craig, Chief, Basin Management Division, and Mr. John Kennelly, Chief, Long Range Planning Section. It was written by Mr. Bill Mullen, Project Manager. Mr. Frank Lucadamo of the National Weather Service's Northeast River Forecast Center in Bloomfield, Connecticut provided extensive input on the role of the NWS in flood warning.

II. FLOOD WARNING AND RESPONSE SYSTEMS

PURPOSES OF FLOOD WARNING AND RESPONSE SYSTEMS

All flood warning and response systems have one or both of the following flood related purposes; the prevention of deaths and injuries, and the reduction in property damages. Flood warning and response systems meet these objectives by providing advance warning of floods to community officials and floodplain residents. This enables the removal of cars and building contents from the path of the expected floodwaters, the closure of roads and bridges that would be expected to flood, the evacuation of the floodplain, and the performance of other flood mitigation response activities.

COMPONENTS OF FLOOD WARNING AND RESPONSE SYSTEMS

There are four critical components of a successfully-operating flood warning and response system: 1. flood threat recognition; 2. flood forecasting and warning message creation; 3. warning message dissemination; and, 4. flood warning response.

1. <u>Flood Threat Recognition:</u>

The flood threat recognition component of a flood warning and response system is the mechanism through which officials are initially made aware of the potential threat of flooding affecting their area. This typically occurs either through an alarm procedure internal to the flood warning system or by notification to the system users from an outside sources.

2. <u>Flood Forecasting and Warning Message Creation:</u>

The flood forecasting and warning message creation component of a flood warning and response system includes the analysis of data in the preparation of a flood forecast(s) for the covered area. The resulting nature and specificity of the forecast will depend upon several factors including the type and design of the system. The warning message created to communicate the forecast must be carefully tailored to the intended audience and should provide explicit instruction on actions to be taken. Information on evacuation routes, emergency shelters, and sources of additional information should be included in the message.

3. <u>Warning Message Dissemination:</u>

The warning message dissemination component of a flood warning and response system is the mechanism of transmitting the warning message to the responsible public officials and the general public, particularly those in the floodplain. Methods of message dissemination may include the use of telephones, police radios, sirens, radio and television broadcasts, and house-to-house notification. The message dissemination procedure may vary with the time of the day, day of the week, forecast lead time, and other factors.

4. <u>Flood Warning Response:</u>

The response component of a flood warning and response system includes all actions taken by the public and private sector to minimize flood related damages. Considerable attention must be given to this aspect since most flood reduction benefits are dependent on the predetermined response to a flood threat. Public officials may use a warning to block off low-lying roads, assist those with special cases (e.g. the elderly, or hospital occupants), ready temporary shelters, or initiate floodproofing measures. The public may respond to the warning by evacuating the floodplain, moving cars and building contents out of the expected path of the floodwaters, or implementing floodproofing measures.

FLOOD PREPAREDNESS PLANS

Although some flood reduction benefit may be achieved without a detailed response plan, maximum benefit from a flood warning system will be obtained if the response to the flood is carefully planned and integrated with capability and limitations of the flood warning hardware. A flood specific preparedness plan thoroughly addresses the warning message dissemination and response components far in advance of a flood. The preparedness plan should address the procedures to be followed before, during, and after a flood event. The flood specific preparedness plan allows the flood emergency to be "managed", as opposed to a flood emergency being merely reacted to. Preparation of preparedness plans is clearly a local responsibility since it is local authorities that perform local emergency response activities.

The preparedness plan should address such matters as who would be notified of an impending flood and in what order, how they would be notified, and the contents of the various warning messages to be issued. The plan should also addresses post-flood cleanup. The plan identifies and prioritizes the objectives of the flood response and should estimate the time and resources required to meet each of the objectives. The response plan should then evaluate the community and private resources likely to be available during a flood and should address any expected shortfall of resources. The plan should thoroughly address evacuation related issues including the legal aspects of requiring an evacuation. The community's role, if any, in mitigating private property damages during a flood should be defined. Roles of all involved government agencies should be identified. The roles and responsibilities identified in the preparedness plan should be formally adopted by the local governing body.

Appropriate levels of response to a flood threat should be planned based on the expected severity of the flood, the time of day the flood would occur, the amount of lead time available, and any other factors which could impact on the response efforts. If found to be appropriate, the flood response may be "staged" with different actions taken as the flood threat progresses. A simple <u>decision tree</u> for the use of the emergency response coordinator should be a goal of this planning process. The preparedness plan should be updated on a regular basis, perhaps annually, to minimize the impact of changes in community personnel, floodplain residents, telephone numbers, response needs, hydraulic conditions, etc.

Facilities in the floodplain requiring special consideration such as elderly housing, hospitals and schools should have their own individualized preparedness plans. In addition, individualized flood audits for commercial and residential structures in the floodplains can be performed to develop a customized emergency response plans. The purpose of the flood audits is to identify what the flood hazard threat means to each of the individual buildings. The first step of a flood audit is to survey the elevation of a building's lowest floor. The various forecasted flood stages can then be translated to depths of flooding at that building. A walk-through of the building should be conducted to determine specific courses of action which the occupant can take to reduce flood losses. A flood audit together with a numeric forecast and sufficient lead time, should enable the occupants to take actions to raise or flood proof building contents and move automobiles out of the floodplain. Flood audit action plans and recommendations should be summarized in a brief one page action plan for use during flood emergencies.

III. NATIONAL WEATHER SERVICE FLOOD FORECAST PROGRAM

GENERAL

The National Weather Service (NWS) is the Federal agency responsible for the formulation and issuance of flood forecasts, watches and warnings in the United States. Forecasts by the NWS vary in their specificity and timeliness, depending primarily upon the length of time for a river or stream to crest. Specific forecasts generally are prepared only for rivers with long crest times. The NWS prepares three types of forecast; 1) river and flood forecasts for major rivers, 2) headwater forecasts for headwater river basins, and 3) flash flood watches and warnings for small streams. The NWS also provides limited assistance to communities in implementing local self-help flood warning systems and statewide flood warning systems.

The NWS currently has 13 River Forecast Centers (RFC), 50 Weather Service Forecast Offices (WSFO), and approximately 200 smaller Weather Service Offices (WSO) throughout the country to prepare its forecasts. This organizational structure is expected to change by the end of the 1990's.

SOURCES OF DATA FOR FLOOD FORECASTING

There are numerous sources of data available for the preparation of flood forecasts ranging from volunteer and paid observers to remotely queried or automatically reporting precipitation and stream flow gages. Observers dispersed throughout the covered area typically measure and report only precipitation data. Observers may be located in the upper headwater areas where the potential for a flood may be detected early in the event. The primary benefits of using observers are their low cost, and ease of recruitment. Utilization of observers to measure and report data, however, may lead to problems with the data's timeliness, gaps in periods of coverage, and human errors in measurement and reporting. In addition, telephone communication links may be broken, particularly during the adverse thunderstorms and other weather events that generally precede floods.

Data Collection Platforms (DCP's) are automated precipitation and river gages, commonly employed by river stage forecasters. DCP's send signals to a receiving computer via the Get Stationary Operational Environmental Satellite (GOES). Signals can be sent in both timed and random (event-triggered) modes, depending on how the DCP's are programmed. The Corps of Engineers in New England owns several DCP's for the purpose of providing data for the operation of various flood control reservoirs.

Another type of remote-reporting gage used by river stage forecasters is the telemark. Telemarks are gages that can be queried via telephone lines to remotely report measured stream stages and precipitation. The gages inform the caller of readings through either beeps, or a synthesized voice. Telemark reporting gages are not designed for automated reporting and, therefore, must be accessed directly by the user.

During the past 10 to 15 years, another type of remote-reporting gage has been developed and improved by the private sector. These gages, both inexpensive and reliable, automatically report gage readings via radio waves to a base station computer/receiver. The computer/receiver unit decodes, displays, and, has the capability to analyze the remotely-reported data. The gages most commonly used for flood warning systems measure precipitation and river stages. These gages can also be constructed as total weather stations designed to also measure wind speed and direction, temperature, and soil moisture.

The automatic reporting precipitation gages employ a tipping bucket assembly that tips each time an incremental unit of rainfall is measured. The tip allows the bucket to empty for reuse, and, at the same time, causes an electrical contact to be made. The electrical contact results in the transmission of a radio wave signal containing the gage station name to the base station computer. It is also possible to program the transmitters to automatically send radio wave signals at predetermined time intervals. Because of their low cost, convenience, and dependability and accuracy when properly maintained, new data sources are being implemented using these automated gages. It is this type of gage that is most commonly used in both local and statewide flood warning systems.

The remote-reporting gages can be used for many purposes other than flood forecasting, including water supply, fire-fighting, dam safety monitoring, and climatologic database expansion purposes.

MAJOR RIVERS AND HEADWATER STREAMS

The NWS provides numeric river stage forecasts for selected forecast points along rivers in the U.S. with crest times occurring 12 hours or more after a heavy rainfall, and for a few points with crest times occurring between 6 and 12 hours. Hydrologists in the thirteen River Forecast Centers (RFC) dispersed throughout the U.S. collect and analyze hydrologic data and run hydrological models to generate the specific flood forecasts for the locations with crest times greater than 12 hours. These forecasts are then released to state Weather Service Forecast Office's (WSFO) for dissemination to the public. Forecasts for these points are prepared and disseminated twice per day during flood situations with the forecasts being released to the WSFOs at approximately 11 A.M. and 11 P.M. Because of the lack of time available for the RFC to perform the various forecast tasks, forecasts for locations that crest from 6 to 12 hours are prepared using less specific headwater forecasts based on simplified hydrologic techniques.

FLASH FLOOD STREAMS

For streams that crest in under 6 hours, the WSFOs release county-wide flood watches that apply to all small streams in the county. A flash flood watch is issued if meteorological conditions indicate that flash flooding of some small streams are possible. If the occurrence of flash flooding is imminent, or is occurring, a flash flood warning is issued. Flash flood warnings are issued by the more local Weather Service Offices (WSO).

NWS MODERNIZATION AND RESTRUCTURING

The NWS has begun a vast modernization effort to take advantage of new technologies and procedures in detecting the precursors of flooding and severe weather. An explanation of the technologies and their ramifications with respect to flood warning is beyond the scope of this study, however, some basic information is provided. The Next Generation Radar (NEXRAD) will be used by the NWS to enhance the quantitative precipitation estimating capabilities of the NWS. Ground level rain gages will still be required for calibration of the NEXRAD estimates. An Automated Surface Observing System (ASOS) will replace current manual data collection methods of obtaining many flood-related weather parameters. The massive amounts of data will be made available to forecasters via the Advanced Weather Interactive Processing Systems (AWIPS). These technologies, along with an associated major restructuring effort, are expected to be fully implemented by the end of the 1990's.

IV. LOCAL AND STATEWIDE FLOOD WARNING AND RESPONSE SYSTEMS

GENERAL NEED FOR FLOOD WARNING SYSTEMS

The NWS flood forecasting procedures appear to meet the demand for flood vulnerable areas located along rivers that crest at least 12 hours after the occurrence of heavy rains. Because of the relatively long lead times available at these points, the NWS has time to collect, analyze, forecast and disseminate specific warnings, and the public has sufficient time to use the warnings for property damage reduction purposes and for evacuating the floodplain. For rivers and streams with lesser lead times, the NWS flood forecasting procedures may not be sufficient to evacuate people from the flood plains and reduce flood damages to residential properties and businesses. Forecasts for these areas are based on rough headwater curves and are not very stage specific. In many cases, the NWS forecasts provide only sufficient lead time to evacuate people from the most vulnerable areas.

For flash flood streams, the NWS does not have the staff nor the resources to prepare anything beyond generic county-wide watches and warnings. Since the watches and warnings apply to all small streams in a county, their value for other than merely precautionary purposes is questionable.

Studies have shown that the more specific a warning and the more imminent the flood, the more likely it is that people will take precautionary actions. Various flood warning systems have been developed by various governmental agencies and the private sector to meet the demand for more timely, accurate, and/or more specific information, local and statewide flood warning systems.

There are two types of flood warning systems discussed in this report; 1) systems designed to provide flood warning to persons in a single drainage basin (i.e. local flood warning systems) and 2) systems designed to provide flood warning throughout multiple river basins in a wide geographic area (e.g. a statewide flood warning system). Either type of flood warning system is potentially a low cost alternative to structural or regulatory solutions, although neither system type can be expected to completely eliminate all flood damages.

LOCAL (ALERT) SYSTEMS

Local flood warning systems with automated data collection capabilities are commonly known as ALERT (Automated Local Evaluation in Real Time) systems. The ALERT system concept was originally developed by the NWS's California-Nevada River Forecast Center, located in Sacramento, California. Because of the combined effects of intense Pacific storms and steep topography of the mountains, even minor streams and normally dry canyons can be transformed into highly hazardous areas. ALERT systems were developed to allow timely warning for these areas which otherwise would receive little, if any, advance warning through the normal NWS procedures.

ALERT systems are designed as stand-alone flood warning systems to monitor flood related data from a single river basin, although limited information may come from outside of the basin. ALERT systems are controlled at the local municipal level and are most commonly employed to assess the flood threat of rivers and streams with drainage areas of approximately between 10 to 150 square miles. ALERT systems are particularly valuable for flood threat recognition occurring for intense local rainstorms. For streams with drainage areas larger than 150 square miles, current NWS forecasting procedures may be sufficient. Local flood warning systems may potentially serve both potential purposes of flood warning: the reduction in flood related injuries and deaths, and the reduction in property damages.

The hardware of ALERT systems includes the inexpensive remote reporting tipping bucket precipitation gages, and usually one or two remote reporting river stage gages. ALERT hardware may also include total weather stations, but do not include DCP's, telemarks, or observers. The rain gages are generally dispersed in the upper reaches of the contributing drainage basin. A river stage gage is usually located at the damage center, and sometimes also at an upstream location on the main stream. The remote reporting gage/transmitter assemblies send line-of-sight radio wave signals to one or more base station computer/receiver units. The base station computers are located at police or fire station facilities staffed around the clock, and located near the flood damage centers. Radio wave repeaters are sometimes required to re-transmit the line-of-sight signals from the gages to the receiving computer(s) because of obstructions or long distances. A simplified ALERT configuration is illustrated in Figure 1. Hardware costs for a small system (drainage area of under 50 square miles) are roughly $30,000 to $35,000.

Data from the ALERT gages, when interpreted by a hydrologist, an experienced system user, or customized hydrological software resident in the receiving computer can potentially be translated into a river stage forecast. The formulation of a numeric forecast depends upon the size of the basin, the system's capabilities and the size of the rainfall event. A numeric stream stage forecast can be a highly desirable part of an local flood warning system. Some ALERT systems are configured to automatically yield, via private vendor software, a numeric forecast of peak stream stage expected at the gage, and the time of the expected peak. Private vendors will perform the significant work needed to set up and calibrate the models. Several years of both precipitation and river stage data are required to calibrate the system before a reliable forecast can be expected. Because an extensive amount of work is required in the setup and calibration of the model, private vendor services can be expensive.

Even without the formulation of a specific numeric stream stage forecast, an ALERT system may allow for early warning of potential flooding. If the base station operators have observed the system in prior flood events and are familiar with the basin, they can make judgements based upon the observed gage readings. Most ALERT systems are also designed with alarm capabilities. The alarm in the base station computer is triggered when data from one or more of the remote gages exceeds a predetermined threshold value or rate. The threshold may be a rate of rainfall occurrence, rate of river stage rise, or a fixed river stage. The alarm may sound hours in advance of a potential flood. When the alarm is sounded, those near the computer are immediately made aware of potentially threatening events. The trained system users should be notified at this point, and early actions in the flood specific emergency response plan may be taken.

It should be noted that to date neither private nor public automated flood stage forecasting ALERT system software has been tested in the New England area.

STATEWIDE SYSTEMS

Statewide flood warning systems, like local flood warning systems, rely on remotely reported precipitation, river stage, and weather data to prepare an early warning of potential flooding. Statewide systems, covering multiple basins, use the same types of remote reporting precipitation and river stage gage hardware employed by ALERT systems and in fact may include ALERT systems as part of the total system. Information from other available sources may also be utilized by a statewide system, including data from DCP's, telemarks, observers, and meteorological sources outside of the covered area. Statewide systems may employ much denser networks of gages than may be available using the NWS resources only.

The NWS has developed one type of statewide flood warning system known as "Integrated Flood Observing and Warning System" (IFLOWS). IFLOWS features centralized system control at the state level, unlike local systems which are controlled at lower levels. With IFLOWS, a macroscopic view of the flood threat is obtained, and relevant information is transmitted to the lower levels every 15 minutes. The type of warnings emanating from the centralized collector/controller is site-specific for some areas, and general for others, similar to that of existing NWS flood forecast products. Two-way communications are allowed by IFLOWS. The predominant purposes of IFLOWS are to shave hours from the existing NWS forecast time for major rivers, headwater streams, and flash flood streams, and to improve the accuracy of the forecasts.

ALERT systems that are part of a statewide system may benefit from the observations of the larger network of gages. Total weather stations that measure wind direction and speed, temperature, and soil moisture for the statewide systems may yield information for state-level users usually not available in ALERT systems. Data from the larger systems may be used to prepare a more accurate flood forecast or increase advance warning time for the local system. Forecasts of additional rainfall expected may be utilized to supplement the readings from the gages.

Statewide flood warning systems can be used for multiple purposes including water management, fire fighting (particularly the wind speed and direction data), radioactive release monitoring, dam failure monitoring, etc. A broad based level of support for a statewide system by other entities enhances a system's chances of long-range success.

NWS SUPPORT OF LOCAL FLOOD WARNING SYSTEMS

The NWS has no national policy concerning their support of local flood warning systems, although it was the NWS who originally pioneered the concept and development of ALERT systems. The Eastern Region Office of the NWS, located in Bohemia, New York, sets policy for the NWS role in the New England area. The Eastern Region Office, in a recent clarification of its policy towards ALERT systems, has stated that it will support such systems only as time and resources permit. This means that the NWS should not be expected to provide a numeric forecast for ALERT forecast points, nor should the NWS be expected to support computer software and hydrologic models developed by other governmental agencies or the private sector. The NWS support of ALERT systems during flood events can best be described as consisting of only limited consultation. This limited support by the NWS in currently deployed ALERT systems in New England has resulted in an under utilization of the capabilities of ALERT systems.

The NWS has developed fully automated forecasting software for the Sacramento Soil Moisture Accounting Model, however, the Region 1 personnel are not able to perform the labor intensive set up and calibration of the this model to the New England region. The NWS will support ALERT systems by supplying simplified manual hydrologic forecast methods for an ALERT forecast point to local users. The accuracy and value of manual forecast methods is somewhat questionable and the use of non-hydrologically trained local officials could lead to problems.

Numeric river stage forecasting for ALERT systems can be performed manually by the NWS on an as resources permit basis. The NWS River Forecast Center in Bloomfield, Connecticut has been involved with the implementation of several ALERT systems in New England. In these cases the NWS prefers to interrogate the data directly and prepare an independent forecast. This forecast is then disseminated through the ALERT system to the end users. If the NWS resources are not available to perform the work, then the local user would be required to prepare a forecast themselves. It is probable that the NWS would be available for forecasting if the storm covers a smaller geographic area, however, during a large general storm event, the NWS may be too involved with other larger river basins to prepare a forecast for an ALERT system covering only a small geographic area. Flood forecasts may also be provided by local trained personnel using manual National Weather Service hydrologic forecasting methods. This study also identified one vendor who prepares around-the-clock customized forecasts during flood events under contractual agreements for counties, communities and other private entities. Whatever the case, the responsibilities of forecast preparation should be formally institutionalized in a Memorandum of Understanding between the NWS and the ALERT community.

NWS SUPPORT OF STATEWIDE FLOOD WARNING SYSTEMS

The NWS's Eastern Region has stated that it supports development of a centralized, statewide approach to flood warning in New England through a system such as IFLOWS. The IFLOWS system, to date, has been implemented in an 200 county region in Kentucky, Virginia, West Virginia, New York, North Carolina, Tennessee, and Pennsylvania. As discussed previously, IFLOWS is a two-way interactive data, text, and sometimes voice communications network that links several dispersed local area computers on a statewide basis. The local area computers receive data from remote sensors the same way as for ALERT systems. The hardware in the field is the same as for ALERT systems, however, the base station computers and software are different. One difference between IFLOWS and ALERT is that, with IFLOWS, the remotely reported real time data from the various sensors is processed at the local computer and then transmitted via radio waves, microwave, telephone, or satellite to the state's controlling computer. Every 15 minutes, the controlling computer sends relevant data and messages back to the local computers. In effect, the state's controlling computer, usually located in the state's Emergency Operations Center, serves as a data and message distribution point for all of the local computers. The state's existing backbone communications network, if existent, is generally adopted for the IFLOWS of a particular state, although the two-way communications feature must usually be added. The NWS hopes for future IFLOWS communications to be entirely by radio wave. It also hopes to create a nationwide networking of IFLOWS systems.

IFLOWS may be considered a top down system, in which the state controls the flow of information. It is unique from state to state, except for the fact that local computers always process the data before being transmitted to the main computer. IFLOWS does assure a uniformity in data and product. IFLOWS uses the NWS-developed software in the controlling computer and the local computers.

At present, IFLOWS software can only handle information from precipitation measuring sensors, although it may soon be modified to accommodate river stage information. Since IFLOWS does not handle river stage data, it cannot be used for river stage forecasting directly. No forecasting options are available in the IFLOWS software. The expertise of hydrologists or hydrometeorologists is still needed to integrate Quantified Precipitation Forecasts and soil moisture indices into a forecast. The "ADVISE" forecast procedure (API runoff model) is used by the NWS with IFLOWS to predict river stages. The ADVISE procedure does not allow hydrologic routing of flows, nor does it have forecast adjustment capabilities. The ADVISE procedure is, therefore not as versatile as usual forecast methods. Standard hydrologic methods are used by the NWS to provide flash flood watches and warnings.

IFLOWS hardware and software is provide through line item funding by Congress and is not part of the NWS budget. No funds are available for the implementation of an IFLOWS flood warning system for at least the next several years. The implementation of IFLOW systems has resulted from major disaster or congressional resolutions for the development of a particular system. The approximate cost of an IFLOWS system is $50,000 per county covered by the system. After an IFLOWS system is implemented, it is turned over to the state for operation and maintenance, with the locals paying the recurring costs.

IFLOWS presently does not have the capability to handle river stage data, therefore, it does not appear to be well suited for the purpose of providing the numeric river stage forecasts required to significantly reduce flood losses. The IFLOWS hardware does incorporate automated remote reporting of precipitation data and two way communications feature which allow for a faster issuance by the NWS of general flash flood watches and warnings. IFLOWS also appears to be better suited for other NWS purposes, such as weather forecasting.

NEW ENGLAND DIVISION EXPERIENCE WITH FLOOD WARNING SYSTEMS

The Corps of Engineers, New England Division (NED) has had some experience with ALERT systems, but not IFLOWS. The New England Division has implemented one ALERT flood warning system for the Pawtuxet River in Warwick, Rhode Island, and recently completed the implemention of another for the Connecticut and Westfield Rivers in West Springfield and Springfield, Massachusetts. Both of these systems are designed to compliment structural and nonstructural solutions to provide a complete flood reduction plan for the study areas. The NWS provided considerable advice and assistance in the Corps formulation of the systems in the early 1980's.

The Warwick ALERT system was implemented in conjunction with the acquisition and demolition of 59 residential structures, the acquisition of 19 privately owned vacant lots, and the raising of utilities from the basements of 17 homes in the Pawtuxet River floodplain. Because the basements of the 17 homes would still be flooded, an ALERT flood warning system was included as part of the plan to give residents time to move damageable property and to evacuate their homes. The ALERT system hardware consists of four remote reporting precipitation gages, three remote reporting stream stage gages and a base station computer located at Warwick's Police Station. The NWS agreed to prepare a flood forecasting model for the basin, but to date has not. The NWS has stated that it is difficult to prepare a hydrologic model for the Pawtuxet River basin because it is so highly regulated. Local authorities have, therefore, not been provided with any mechanism for flood forecasting, nor has a flood specific emergency response plan been developed. Many of the system's remote reporting gages have been repeatedly vandalized and then repaired.

The West Springfield/Springfield ALERT system is being implemented in conjunction with the raising of 3400 feet of the Corps' West Springfield Local protection Project. The purpose of the flood warning system is two fold; to save lives by timely evacuation of the floodplain and to allow some damage reduction by the moving of items out of the path of the floodwaters. According to the NWS, an increased warning time for both the Connecticut and the Westfield Rivers is also expected to result from the implementation of this system. For the Connecticut River, no new gages are being implemented, however, the lead time for West Springfield for the existing Connecticut River forecast point at Springfield should be increased. For the Westfield River, four precipitation and two river stage gages have been located in the basin to remotely-report to the base station computer located at in a West Springfield Fire Station.

NED has monitored the experiences that State of Connecticut, Department of Environmental Protection (DEP), has had with their statewide flood warning system called Automated Statewide Evaluation in Real Time (ASERT). Connecticut's Committee on Automated Flood Warning implemented the statewide network of remote reporting sensors in 1985-1986. The ASERT system provides two primary functions; to facilitate an early state and municipal response to flood events and to obtain data for the state's meteorological and climatological data base. The ASERT system was paid for and implemented primarily by the state. Although the ASERT system is based on ALERT type technology, the system performs similar to the NWS IFLOWS system. The only real difference is the lack of a two way communications system. Individual ALERT systems are being linked to the ASERT system in order to obtain specific river stage forecasts at various locations not currently receiving a forecast.

The ASERT system enables flood event response through the state and the NWS monitoring and detection of weather events capable of producing floods. Warnings of potential flooding are subsequently issued to municipalities with and without local flood warning systems. Municipalities with local flood warning systems may receive site specific warnings, while those without local systems may receive general warnings. The ASERT system presently consists of 22 remote reporting precipitation gages, 6 remote reporting weather stations, 6 repeater sites, and two base stations with computers that receive and decode the signals. Base stations are located at the DEP's Water Resource Unit office in Hartford, Connecticut, and at the RFC facility in Bloomfield, Connecticut. The DEP and RFC base stations receive ASERT and ALERT system gage data via line-of-sight radio waves and radio wave repeaters.

The local ALERT flood warning systems linked to the ASERT system, also have base station computers. The local base station computers generally receive only data from the gages in the contributing drainage basin and its vicinity. Communication between the NWS, the Connecticut DEP, and the local system users are by telephone, with backup communications between the local systems and the RFC by the National Warning System (NAWAS).

The ASERT system initially included two ALERT systems to test the system for numeric river stage forecasting purposes. ALERT systems were implemented for the Yantic River in Norwich, Connecticut and for the Quinnipiac River in Southington, Connecticut. Norwich's ALERT system consists of 4 precipitation gages and 1 river stage gage which remotely transmit data to the city's two ALERT base stations. Southington's ALERT system consists of 3 remote-reporting precipitation gages, a river stage gage which can be queried over the telephone lines, and a base station located in their City hall. Other systems linked to the ASERT system since that time include Hartford, Connecticut's ALERT system and Stamford, Connecticut's ALERT system, and the water supply monitoring system of the South Central Connecticut Regional Water Authority. The state hopes to eventually link nearly twenty-five ALERT systems up to ASERT.

The State provides comprehensive support to the system and assistance to the local users. The State pays a significant share of the ALERT system hardware costs and all of its maintenance costs, monitors all of the state's gage readings, and serves as a link between the NWS and the local users. The State also provides two full time technicians with the responsibility of maintaining all of the remote reporting gages in the ASERT system.

Users of the data from the ASERT system also include the Connecticut DEP Forestry Unit, the Connecticut DEP Natural Resources Center, dam safety personnel at the Connecticut DEP Water Resources Unit, and the NWS weather forecasters.

V. COMPARISON OF LOCAL VERSUS STATEWIDE SYSTEMS

INTRODUCTION

One of the primary objectives of this report is to discuss the options available to the Commonwealth of Massachusetts to improve existing flood warning and response capabilities in order to reduce the potential for loss of life and to reduce flood damages. This report has identified and discussed two alternative flood warning system approaches. The Commonwealth must define the level of flood warning required throughout the State and select a suitable flood warning and response approach. This requires the evaluation of the current level of flood warning capability and the determination of the required improvements. If the overall coverage provided by the NWS is sufficient and the existing problems are principally associated with isolated areas or small drainage basins, the Commonwealth may choose to implement local ALERT systems. If the flood warning problems are more widespread, then a statewide system may provide a better solution than local ALERT systems.

One of the fundamental issues the Commonwealth needs to address is the desired purpose of flood warning. If the principal objective of a flood warning and response system is to facilitate the safe evacuation of vulnerable areas, then a simplistic warning system may be sufficient. This type of system could consist of a simple flash flood alarm system with only a single upstream river stage gage. If an important goal, however, is the reduction of flood damages, then a more complex numeric river stage forecast system may be required.

The advantages, disadvantages, capabilities, and limitations of local and statewide flood warning systems must be clearly understood to properly select a flood warning approach to address the Commonwealth's needs. Some of the issues associated with the two systems are discussed in the following sections.

ADVANTAGES OF LOCAL FLOOD WARNING SYSTEMS

Local ALERT systems can be relatively inexpensive ways of reducing the potential for loss of life and reducing flood related damages for specific areas. This is accomplished by providing advanced warning of the potential for flooding at a predetermined floodplain damage center. The advanced warning is used in conjunction with a flood preparedness plan to evacuate vulnerable areas and allow time to implement flood damage reduction measures. The hardware associated with these systems is relatively inexpensive, costing approximately $30,000 to $35,000 for a small drainage area.

Local ALERT systems may be the only way to achieve specific forecasts, particularly for locations with contributing drainage areas of under 150 square miles. Local ALERT systems have the capability of yielding either a flood stage specific or a generalized forecast. The ultimate forecast for a system would be a timely and site-specific forecast of all floods at the damage center, however, the type of forecast may be limited by the size and complexity of the basin. In some cases, a stage specific forecast may not be possible. The type of forecast will depend on what is required to meet the needs of the vulnerable area.

Local ALERT systems can be implemented relatively quickly and simply, with only limited assistance and coordination from other entities. Private firms are available to assist in the design, installation, modelling and calibration of an ALERT system for a floodplain area. Only limited assistance should be expected from the NWS.

ISSUES ASSOCIATED WITH LOCAL FLOOD WARNING SYSTEMS

The importance of the system calibration and maintenance aspects of local flood warning systems cannot be stressed enough. The entity responsible for the local ALERT system must perform the system calibration and maintain the equipment themselves or hire someone to perform these tasks for them. A fairly high degree of technical skill is required to perform the required system calibration. These skills are typically not found at the local level and it may be expensive to hire someone with the required technical skills. Remote reporting flood warning hardware typically has a life expectancy of approximately 15 years, therefore, the system will require periodic replacement. The system components are also remotely located and can be subjected to damage from weather and vandalism unless located in secure places with appropriate protective devices.

A comprehensive flood specific preparedness plan, addressing how a warning would be utilized, must be developed to obtain significant benefits. If the major effort in preparing a plan is not undertaken, benefits from the system will likely be minimal. Preparedness planning performed for relatively infrequent events, requires a long range outlook. The enthusiastic involvement of local officials may be hard to obtain for an event that occurs only rarely. Enthusiasm and support for a Local ALERT system is bound to reach a high following a flood event, and then wane with the passage of time.

Funds for the replacement of all system hardware and its software must be provided for, as well as funds for system calibration, maintenance and upgrading. Systems may become neglected and under funded during periods of infrequent use. Long range funding commitments of these aspects may be difficult to expect from smaller communities.

The automated forecasting capabilities of ALERT systems has been questioned for small river basins in New England. Forecasters from the Northeast River Forecast Center have stated that unadjusted forecasts from automated forecasting software, or NWS-supplied manual methods may be inaccurate, or suitable only for the forecast of the general magnitude of a flood. The principal concerns are the accounting of antecedent conditions and the importance of incorporating Quantified Precipitation Forecasts into the river stage forecasts. Since there is little experience with automated flood forecasting systems in the region, it is not clear if these concerns are valid or if means are available to account for these factors. Since there is a trade off between forecast accuracy and available warning time, an assessment of the value of earlier unadjusted, less accurate forecasts versus later adjusted, more accurate forecasts must be made relative to the specific damage center.

DISADVANTAGES OF LOCAL FLOOD WARNING SYSTEMS

The implementation of a Local ALERT system requires one or more trained system users within the community. If there is high turnover in local governments, the training of the users may pose a problem. Several years of data collection and evaluation experience with a local flood warning system are required before the capability of the system are realized. It is important that forecast procedures be institutionalized in formal Memorandums of Understanding, or the forecast procedures may not be performed during the confusion usually accompanying flooding events. It is also recommended that periodic system exercises be performed to ingrain these procedures.

The general lack of support for local systems by the National Weather Service is a disadvantage. ALERT systems may have experienced apparent success in the West primarily because individual NWS employees have taken an active interest in the systems.

The local ALERT system typically requires remote gages located outside of the political boundaries of the damage center. This requires the entity responsible for the system to enter into negotiations with a second political entity for land rights for the remote reporting hardware. If the upstream community does not somehow gain from the granting of these rights, the acquisition of the land rights may be difficult.

ADVANTAGES OF STATEWIDE FLOOD WARNING SYSTEMS

The implementation of a statewide flood warning system has several advantages. Existing gaps in geographic coverage may be filled and flood producing events can be tracked on a larger level. The State may be able to provide river stage forecasting assistance that the NWS is unable to provide. The state would provide the services of one or two full time experienced technicians and/or operators with the required experience and skill level to maintain the hardware. Land rights for the remote reporting hardware might be negotiated more successfully by the State.

A statewide flood warning system improves upon the existing flood forecast system of the National Weather Service. Because IFLOWS has the full support of the NWS, there may be a better opportunity for long range system support. The IFLOWS system, in particular, has value to emergency response personnel because of its communication features. For the slower cresting rivers, a statewide system allows more timely numeric river stage forecasts that are also more accurate due to the denser network of gages. For the flashier streams, flash flood watches and warnings are formulated quicker.

ISSUES ASSOCIATED WITH STATEWIDE FLOOD WARNING SYSTEMS

The NWS supported IFLOWS type of statewide flood warning system does not alter the nature of the forecast product available. The general flash flood watches and warnings facilitate no more specific actions than that at present since the forecasts are not numeric. IFLOWS facilitates the instant collection of only raw rainfall data. There are no river stage forecast features available. The system does not necessarily result in an increased number of forecast points; it only increases the lead time before the flood. The IFLOWS system appears better designed to serve the weather forecasting roles of the NWS, not river stage forecasting roles.

DISADVANTAGES OF STATEWIDE FLOOD WARNING SYSTEMS

Statewide flood warning systems are slow to plan and implement because of the required Congressional and Administration approval and funding. If the Commonwealth determined that the best flood warning approach was the implementation of an IFLOWS system, there is no guarantee that funding would be available. Discussions with the NWS indicate that funding for the implementation of a new IFLOWS system would not be available for at least three (3) years.

After the implementation of an IFLOWS system, the operation and maintenance of an IFLOWS system becomes a state responsibility after it is installed. This may be difficult for the Commonwealth to undertake during these times of limited personnel resources and increasing budgetary constraints.

VI. FLOOD WARNING AND RESPONSE IN MASSACHUSETTS

EXISTING FLOOD FORECAST AND DETECTION CAPABILITIES

The National Weather Service's Northeast River Forecast Center (NERFC) in Bloomfield, Connecticut, is charged with the responsibility of predicting the flows of the major rivers throughout New England. The Northeast River Forecast Center issues river stage forecasts for seventeen locations in Massachusetts with drainage areas ranging in size from 35 to 9,587 square miles. Table 1 lists the locations in Massachusetts for which river stage forecasts are prepared and Figure 2 is a map showing their locations. Data used by the NERFC to prepare these forecasts is collected from nearly thirty precipitation observers and five stream stage observers dispersed throughout Massachusetts.

In addition to the observers, the NERFC uses data from five remote reporting precipitation gages and from several remote stream stage gages. Table 2 lists all of the remote reporting gages in the state and Figure 3 is a map showing their locations. With the exception of the precipitation and stream stage gages installed by the Corps for the West Springfield flood warning system, none of these gages are available for incorporation into ALERT systems without modifications. The data currently being remotely reported from these gages is not in a format that can be read by the ALERT computers. The remote data is now obtained either by telephone line (telemarks) or through Data Collection Platforms (DCPs) that transmit data via the Geostationary Operational Environmental Satellite (GOES). The Corps and the US Geological Survey (USGS) both have the capability to receive GOES data. Most of the remote reporting gages are owned by the USGS. The Corps of Engineers has equipped nine USGS gages and two of its own river stage gages with DCPs and uses the information in the regulation of its reservoirs.

DISSEMINATION OF FLOOD WARNING

At present, the only agency that issues flood forecasts for areas in Massachusetts (including the West Springfield ALERT system) is the National Weather Service, primarily through the Northeast River Forecast Center. Only the dissemination of warning from the NERFC is discussed in this section.

The New England River Forecast Center generally issues forecasts twice per day during flood situations and once per day during normal conditions. When the New England River Forecast Center issues a forecast, it is typed into a communications computer known as AFOS (Automation of Field Operations and Services), which relays the forecast to a network called NWWS (NOAA Weather Wire Service). This circuit automatically prints out the forecast at several locations, including a teletype machine located at Massachusetts Civil Preparedness Headquarters in Framingham. The headquarters is fully staffed eight (8) hours per day and has security people that notify the proper Civil Preparedness agency personnel when

TABLE 1 – STREAM-STAGE FORECAST POINTS IN MASSACHUSETTS

NO	HYDR UNIT NUMBER	TOWN	RIVER	GAGE NO.	D.A.	OWNER	GAGE	LATITUDE	LONGITUDE	LOCATION
1	01070002	LOWELL	MERRIMACK	01100000	4635	USGS	DCP(COE), TM	42 38'45"	71 17'56"	1100 FT D/S CONCORD R.
2	01070002	LAWRENCE	MERRIMACK		4672	POWER	STAFF			
3	01070002	HAVERHILL	MERRIMACK		4900		STAFF			
4	01070004	LEOMINSTER	N NASHUA	01094500	110	USGS		42 30'06"	71 43'23"	1.3 MI U/S WEKEPEKE BROOK
5	01070004	EAST PEPPERELL	NASHUA	01096500	435	USGS	DCP(COE), TM	42 40'03"	71 34'32"	200 FT D/S POWERPLANT; 0.8 MI U/S NISSITISSIT R; WILL BE RELOCATED D/S TO NASHUA, N.H.
6	01070005	MAYNARD	ASSABET	01097000	116	USGS	STAFF	42 25'55"	71 27'01"	150 FT U/S HWY 27 BRIDGE; 1.7 MI D/S ASSABET BROOK
7	01070005	LOWELL	CONCORD	01099500	400	USGS	TM	42 38'12"	71 18'09"	300 FT D/S ROGERS ST. BRIDGE; 0.3 MI D/S RIVER MEADOW BROOK; 0.8 MI U/S MOUTH
8	01080201	MONTAGUE CITY	CONNECTICUT	01170500	7860	USGS	DCP(COE), TM	42 34'48"	72 34'30"	75 FT D/S RR BRIDGE; 1000 FT D/S DEERFIELD R.
9	01080201	NORTHAMPTON	CONNECTICUT				STAFF			
10	01080201	HOLYOKE	CONNECTICUT		8177		TM			
11	01080204	INDIAN ORCHARD	CHICOPEE	01177000	688	USGS	DCP(COE), TM	42 09'38"	72 30'52"	1000 FT D/S WEST ST BRIDGE; 1.1 MI U/S FULLER BROOK; INDIAN ORCHARD
12	01080205	SPRINGFIELD	CONNECTICUT		9587	SPFLD	STAFF			
13	01080206	WESTFIELD	WESTFIELD	01183500	497	USGS	DCP(COE), TM, ALERT	42 06'24"	72 41'58"	0.7 MI D/S GREAT BROOK
14	01090001	NORWOOD	NEPONSET	01105000	35	USGS	DCP	42 10'39"	71 12'05"	200 FT U/S PLEASANT ST. BRIDGE; 200 FT D/S RR BRIDGE; 0.45 MI D/S HAWES BROOK
15	01090001	DOVER	CHARLES	01103500	183	USGS	DCP, TM	42 15'22"	71 15'38"	0.3 MI D/S HWY. BRIDGE; 0.8 MI D/S NOANET BROOK
16	01090003	NORTHBRIDGE	BLACKSTONE	01110500	139	USGS	DCP(COE), TM	42 09'13"	71 39'09"	100 FT D/S SUTTON ST. BRIDGE
17	01100005	GREAT BARRINGTON	HOUSATONIC	01197500	282	USGS USGS	TM	42 13'55"	73 21'19"	ON U/S SIDE OF BRIDGE AT VAN DEUSENVILLE; 0.5 MI U/S WILLIAMS R.

NOTE: NUMBERS SHOWN IN FIRST COLUMN REFER TO NUMBERS SHOWN ON FIGURE 2

ABBREVIATIONS: U/S = UPSTREAM
D/S = DOWNSTREAM
DCP = DATA COLLECTION PLATFORM (VIA SATELLITE)
TM = TELEMARK (VIA TELEPHONE LINES)

TABLE 2 - REMOTE-REPORTING STREAM STAGE AND PRECIPITATION GAGES IN MASSACHUSETTS

NO.	HYDROLOGIC UNIT NO.	TOWN	RIVER	GAGE NO.	D.A.	OWNER	GAGE	TYPE	NWS FORECAST	LATITUDE	LONGITUDE	LOCATION
1	01070002	LOWELL	MERRIMACK	01100000	4635	USGS	DCP(COE), TM	S	YES	42 38'45"	71 17'56"	1100 FT D/S CONCORD R.
2	01070004	FITCHBURG	N NASHUA	01094400	63	USGS	DCP	S	NO	42 34'34"	71 47'19"	400 FT U/S FIFTH ST. BRIDGE;1.8 MI U/S BAKER BK
3	01070004	LEOMINSTER	N NASHUA	01094500	110	USGS		S	YES	42 30'06"	71 43'23"	1.3 MI U/S WEKEPEKE BROOK
4	01070004	EAST PEPPERELL	NASHUA	01096500	435	USGS	DCP(COE), TM	S	YES	42 40'03"	71 34'32"	200 FT D/S POWERPLANT; 0.8 MI U/S NISSITISSIT R; TO BE RELOCATED D/S TO NASHUA, N.H.
5	01070005	LOWELL	CONCORD	01099500	400	USGS	TM	S	YES	42 38'12"	71 18'09"	300 FT D/S ROGERS ST. BRIDGE; 0.3 MI D/S RIVER MEADOW BROOK; 0.8 MI U/S MOUTH
6	01080201	MONTAGUE CITY	CONNECTICUT	01170500	7860	USGS	DCP(COE), TM	S	YES	42 34'48"	72 34'30"	75 FT D/S RR BRIDGE; 1000 FT D/S DEERFIELD R.
7	01080201	HOLYOKE	CONNECTICUT		8177		TM	S	YES			
8	01080202	WINCHENDON	PRIEST BROOK	01162500	19	USGS	DCP	S	NO	42 40'57"	72 06'56"	100 FT D/S HWY BRIDGE
9	01080202	TULLY DAM T.W.	E BR TULLY	01165000	51	USGS	TM	S	NO	42 38'32"	72 13'34"	300 FT D/S TULLY DAM; 1.3 MI D/S LAWRENCE BROOK
10	01080202	ATHOL	MILLERS		280	COE	DCP	S	NO	42 35'40"	72 14'45"	AT MAIN ST. BRIDGE IN ATHOL
11	01080203	CHARLEMONT	DEERFIELD	01168500	361	USGS	TM	S	NO	42 37'33"	72 51'20"	2.5 MI D/S CHICKLEY R.
12	01080203	WEST DEERFIELD	DEERFIELD	01170000	557	USGS	DCP(COE)	S	NO	42 32'09"	72 39'14"	0.4 MILES D/S SOUTH R.
13	01080204	HARDWICK	E BR SWIFT	01174500	44	USGS	DCP	S	NO	42 23'36"	72 14'21"	100 FT U/S SPILLWAY REGULATING DAM
14	01080204	BARRE FALLS T.W.	WARE	01172500	55	USGS	TM	S	NO	42 25'35"	72 01'30"	700 FT D/S BARRE FALLS RES.;1.6 MI U/S BURNSHIRT R.
15	01080204	BARRE PLAINS	WARE		115	COE	DCP	S	NO	42 22'52"	72 07'15"	AT RTE. 32 BRIDGE IN BARRE PLAINS
16	01080204	GIBBS CROSSING	WARE	01173500	197	USGS	DCP(COE)	S	NO	42 14'10"	72 16'23"	0.5 MI U/S GIBBS CROSSING;1.8 MI U/S BEAVER BK
17	01080204	INDIAN ORCHARD	CHICOPEE	01177000	688	USGS	DCP(COE), TM	S	YES	42 09'38"	72 30'52"	1000 FT D/S WEST ST BRIDGE; 1.1 MI U/S FULLER BROOK; INDIAN ORCHARD
18	01080206	BECKET	WESTFIELD			COE		P	---			TURNPIKE MAINTENANCE AREA
19	01080206	W SPFLD	WESTFIELD			COE		P	---			BEAR HOLE RESERVOIR
20	01080206	HUNTINGTON	WESTFIELD			COE		P	---			LITTLEVILLE LAKE
21	01080206	BLANDFORD	WESTFIELD			COE		P	---			TURNPIKE MAINTENANCE AREA
22	01080206	HUNTINGTON	W BR WESTFIELD	01181000	94	USGS	TM,ALERT	S	NO	42 14'14"	72 53'46"	0.4 MI D/S ROARING BROOK; 1.5 MI U/S MOUTH
23	01080206	WESTFIELD	WESTFIELD	01183500	497	USGS	DCP(COE), TM,	S	YES	42 06'24"	72 41'58"	0.7 MI D/S GREAT BROOK
24	01080207	NEW BOSTON	W BR FARMINGTON	01185500	92	USGS	TM	S	NO	42 04'45"	73 04'24"	5 FT D/S HWY BRIDGE; 0.3 MI D/S CLAM RIVER
25	01090001	NORWOOD				NWS		P	---			NORWOOD AIRPORT
26	01090001	NORWOOD	NEPONSET	01105000	35	USGS	DCP	S	YES	42 10'39"	71 12'05"	200 FT U/S PLEASANT ST. BRIDGE; 200 FT D/S RR BRIDGE; 0.45 MI D/S HAWES BROOK
27	01090001	IPSWICH	IPSWICH	01102000	125	USGS	DCP	S	NO	42 39'35"	70 53'39"	200 FT D/S WILLOWDALE DAM; 1.5 MI D/S HOWLETT BK
28	01090001	DOVER	CHARLES	01103500	183	USGS	DCP, TM	S	YES	42 15'22"	71 15'38"	0.3 MI D/S HWY. BRIDGE; 0.8 MI D/S NOANET BROOK
29	01090001	WALTHAM	CHARLES	01104500	227	USGS	DCP	S	NO	42 22'20"	71 14'03"	800 FT D/S MOODY ST. BRIDGE;0.3 MI U/S BEAVER BK
30	01090003	NORTHBRIDGE	BLACKSTONE	01110500	139	USGS	DCP(COE), TM	S	YES	42 09'13"	71 39'09"	100 FT D/S SUTTON ST. BRIDGE
31	01090004	NORTON	WADING	01109000	43	USGS	DCP	S	NO	41 56'51"	71 10'38"	200 FT D/S HWY 140 BRIDGE;0.9 MI U/S CONFL RUMFORD R.
32	01100001	WEBSTER	FRENCH	01125000	85	USGS	DCP(COE), TM	S	NO	42 03'03"	71 53'08"	50 FT U/S PLEASANT ST. BRIDGE;1.1 MI U/S POTASH BR
33	01100005	GREAT BARRINGTON	HOUSATONIC	01197500	282	USGS	TM	S	YES	42 13'55"	73 21'19"	ON U/S SIDE OF BRIDGE AT VAN DEUSENVILLE; 0.5 MI U/S WILLIAMS R.
34	02020003	WILLIAMSTOWN	HOOSIC	01332500	126	USGS	DCP	S	NO	42 42'01"	73 09'34"	0.3 MI D/S SHERMAN BROOK

NOTE: NUMBERS SHOWN IN FIRST COLUMN REFER TO NUMBERS SHOWN ON FIGURE 3

ABBR EVIATIONS: U/S = UPSTREAM
D/S = DOWNSTREAM
DCP = DATA COLLECTION PLATFORM (VIA SATELLITE)
TM = TELEMARK (VIA TELEPHONE LINES)

necessary during the remaining hours. A recent development in forecast issuance in Massachusetts is the use of satellite and computer terminals to quickly transmit and receive messages.

The Massachusetts Civil Preparedness headquarters facsimile the forecast to the responsible Civil Defense Area Office (Area 1 in Tewksbury, Area 2 in Bridgewater, Area 3 in Westboro, and Area 4 in Belchertown) and to other key locations. The Area Offices are staffed 8 hours per day and when not staffed have answering machines that give telephone numbers to call in an emergency. The Area Offices notify the local Civil Preparedness Directors via telephone. In emergencies, warnings can be transmitted over the State Police's Law Enforcement Teletype System.

Those directly affected by a flood can receive flood warnings in a variety of ways. Typically, once a community is informed by the Area Office or from other sources of a potential flood event, police or fire personnel are dispatched to warn vulnerable residents and businesses in the area. For rivers with large drainage areas, sufficient warning time is generally available to evacuate flood prone areas and perform flood damage reduction measures. However, for smaller drainage areas the available warning time may only allow for the evacuation of the areas.

Dissemination of warnings from local ALERT systems preparing their own forecasts will have to be determined in the preparation of flood specific preparedness plans on a site and agency specific basis.

VII. ECONOMIC ASSESSMENT OF FLOOD WARNING

GENERAL

This portion of the report investigates the benefits and costs of flood warning systems on a basin by basin level to determine the overall need for improved flood warning and response for flood prone areas in Massachusetts and to identify those basins that potentially could be candidates for flood warning systems. The benefits and costs of flood warning systems presented in this report were calculated using existing flood damage data and rough design and cost estimating techniques. The results of this analysis should only be used to evaluate the relative need for flood warning systems for individual locations and should not be used for purposes of system design or project economic justification.

6.2 DATA USED

The analysis contained in this report uses existing average annual flood damage data compiled in the mid-1970's by the U.S. Soil Conservation Service (SCS) for the Commonwealth of Massachusetts. The results of the SCS analysis were published in a major four-volume report (Refs. 13 to 16) known as the Massachusetts Water Resources (MWR) Study. A separate volume was prepared for each of the following four regions located in the state; 1) the Berkshire Region, 2) the Connecticut River Region, 3) the Central Region, and 4) the Coastal Region. Each of the four regions included several basins with boundaries that differ only slightly from those officially adopted by the Commonwealth of Massachusetts (Ref. 2). The basins are further subdivided into sub-basins. In the MWR Study, the average annual flood damages were listed by sub-basin. The flood damage data used in the analysis has been adjusted to reflect the affects of Corps and SCS projects constructed after the compilation of the SCS data. All damage estimates have been updated to 1992 dollars. The MWR report did not include damage estimates for sub-basins with damages less than $10,000.

The Hydrologic Basin Diagrams shown in Figures 5 through 27 show the hydrologic order of the sub-basins (two letter abbreviation e.g. HU) in each basin for which the average annual flood damage data was estimated. For example, in Figure 5, sub-basins HU-1 (the Hoosic River), HU-3 (Hudson Brook) and HU-4 (the Green River) all flow into sub-basin HU-2 (the Hoosic River). Sub-basin HU-1 has a drainage area (DA) of 47 square miles and average annual damages (AAD) of less than $10,000 for the entire sub-basin. HU-1 flows into HU-2 at the upstream end of HU-2, while HU-3 (DA = 7 square miles and AAD = $14,000) flows into HU-2 a short distance downstream. HU-4 (DA = 43 square miles and AAD = $321,000) flows into HU 2 near its most downstream point. The DA for HU-2 includes the DA for ALL of the area upstream from its most downstream point. The AAD for HU-2 is only for the area covered by HU-2 itself.

The code designations (e.g. "HU-3") used in the Hydrologic Basin Diagrams are unchanged from those used in the original MWR Study, however, occasionally a sub-basin name (e.g. Hudson Brook) was changed to better describe the sub-basin. In such cases, the original sub-basin name is shown in parentheses immediately following the revised name.

In addition to the average annual damage and drainage area size data, the Hydrologic Basin Diagrams note the substantial flood control dams constructed by the Corps of Engineers, the current NWS river stage forecast points, and the existing remote reporting gage sites.

Hydrologic Basin Diagrams were not prepared for several river basins where either the average annual flood damages for its sub-basins were less than $10,000 or where the basin drains into the ocean or another state without a single exit point from the basin.

The SCS did not document the methodology used to estimate the average annual flood damages in the MWR Study. Verbal conversation with SCS personnel indicates that the reports included existing damage data derived by the SCS field offices, supplemented by reconnaissance level field investigations. The data therefore should be considered preliminary in its accuracy.

The SCS estimated average annual flood damages for sub-basins in which flood damage reducing projects have been constructed since the mid-1970's were adjusted by subtracting the estimated annual benefits of the project. This information was obtained either from the Corps' project Design Memorandums or through verbal conversation. Sub-basins for which the damage values have been reduced by the recent projects are indicated in the "Notes" part of the Hydrologic Basin Diagrams. The Corps of Engineers had existing flood damage data for three sub-basins (WE-39, WE-42, and WE-44) in the Westfield River basin. This information was used in place of the existing MWR report. Although the damage values provided by SCS in the MWR Study are somewhat dated, they are the most up to date existing flood related values of uniform format for the entire state.

METHODOLOGY

For purposes of this analysis, the average annual flood damages were assumed to occur at or near the most downstream point in the sub-basin since the size of each of the sub-basins is relatively small. Reduction in flood related damages as measured in dollars were used as the benefits of a flood warning system. Because of the uncertainty of predicting lives saved or injuries reduced, such savings were not quantified and were not counted as measurable benefits in this report. Although not quantified, they are very real benefits of a flood warning system.

Benefit Analysis:

The methodology used in quantifying the benefits of a flood warning system was based on the observation that an increase in warning time of an impending flood leads to a reduction in flood related damages. The reduction in damages largely is caused by residents of the floodplain raising movable contents in the home out of the path of the forecasted floodwaters. The relationship of warning time to the reduction in total damages is shown by the curve shown on Figure 4. The relationship was based on a study of residential flood damages along five river reaches (four in Pennsylvania and one in New York) and an assumption of 100 percent response. It does not include damage reduction by moving automobiles out of the path of the forecasted floodwaters. Moving automobiles is a simple and quick way of reducing a large amount of damages. Damage reduction may be greater for commercial and industrial structures than that indicated by the curve because of their typical storage of stock and contents on the first floor and sometimes the higher number or value of contents. The relationship shown by the curve was, however, used without modification.

Warning time provided to a sub-basin was based on a rule-of-thumb equation used by the National Weather Service to estimate a basin's time of concentration. Time of Concentration is defined as the time it takes for a drop of water at the hydrologically most distant point in a basin to reach the mouth of the basin. Warning time with a flood warning system for a sub-basin is assumed to equal the sub-basin's time of concentration minus 75 minutes. The 75 minutes includes the time elapsed in collecting the rainfall data, the forecast preparation time, and the time to disseminate the warning to the floodplain residents. It was also assumed that the floodplain residents currently receive an average warning 45 minutes prior to the peak of the flood. The increase in warning time used in this analysis to calculate benefits of a system is thus the sub-basin's time of concentration minus the time for forecast preparation and dissemination and minus the existing warning time. The curve shown in Figure 4 was then used to yield a percent reduction in total flood damages for each sub-basin using the increased warning time.

The benefits of a flood warning system were calculated by multiplying the percent reduction in total damages by the average annual damages to yield an average annual benefit for each river basin. Reduction in damages were not calculated for locations where the Northeast River Forecast Center currently prepares forecasts.

<u>Cost Analysis:</u>

The methodology used in quantifying the costs of a flood warning system was based in part on a rule-of-thumb equation used by the National Weather Service in determining the number of remote reporting gages needed for a flood warning system. In the estimation of costs, it was assumed that there would be one combination precipitation/river stage gage with the remainder of the gages being precipitation gages. It was assumed that one radio wave repeater would be needed to receive remote gage data at the base station and that the National Weather Service will provide the manual forecast tools without cost to the community. A fifteen year equipment life and a ten percent interest rate was used. Hardware maintenance costs were assumed to be fifteen percent of the initial hardware cost each year. Cost of the hardware, including installation, was based on an estimate prepared by a hardware vendor for a twenty square mile river basin in Connecticut (see Appendix A). A ten percent contingency cost was added to the system's initial cost. The cost of preparing and adopting a flood specific emergency preparedness plan was not included in the calculation of costs, nor was the cost of preparing, and calibrating a forecasting model. It should be noted that flood warning systems were considered as being independent systems in all cost calculations. The report does not factor the potential sharing of costs between sub-basins that might use some of the same remote reporting gages. The flood warning hardware and ongoing hardware maintenance costs were converted to average annual costs for each sub-basin.

Benefit-Cost Analysis:

A benefit cost ratio was calculated for each sub-basin by dividing the average annual benefits of a flood warning system by the average annual costs. A benefit cost ratio of greater than one indicates a likely cost effective use of funds since each dollar spent on a flood warning system should save more than a dollar. The calculated benefit cost ratios were based partly on rules-of-thumb and thus should be considered valid only for screening purposes. A flood warning system should not be rejected for detailed analysis in the future merely because it has a benefit cost ratio of less than one because of the rough method of estimating benefits and costs and because cost sharing by sub-basins was not considered.

Some of the sub-basins examined have drainage areas larger than that usually associated with ALERT type systems. In many of these cases, the River Forecast Center already prepares a forecast for a point in the sub-basin. Installation of ALERT-type hardware in the sub-basin may, however, increase the timeliness and accuracy of the forecast. It is likely that the implementation of an effective warning and preparedness plan using the forecast prepared by the NERFC would result in a lessening of the flood damages. In such cases, a more effective use of funds might be in the preparation of a plan and not in the purchase of hardware.

Sub-basins with a drainage area size of under ten square miles were not analyzed. It was assumed that the advance flood warning time would be too small to make effective use of the time. No analysis was made of basins sustaining less than $10,000 of average annual flood damages since the Soil Conservation Service did not estimate average annual flood damages. The Connecticut, Merrimack and Charles River mainstems were not analyzed since forecasts for these rivers are already prepared by the Northeast River Forecast Center.

RESULTS OF ANALYSIS

Results of the analysis using the data and methodology described previously are shown in Tables 3 through 6.

Berkshire Region:

Table 3 presents the benefits to costs analysis for a flood warning system for the Berkshire Region. The Berkshire Region, which includes the Hudson (Hoosic) and Housatonic River basins, has a total of 5 sub-basins having benefit-cost (B/C) ratios of one or greater when the sub-basins are independently examined. The following locations were identified as potential flood warning system candidates;

Location	Basin Code	Benefit/Cost Ratio
Green River	HU-4	5.3
Southwest Br. Housatonic River	HO-2	1.6
East Branch Housatonic River	HO-3	1.0
	HO-4	6.8
Housatonic River	HO-9	1.5

There is great potential for sharing of hardware costs for a flood warning system between the described basins in the Housatonic River Basin. This potential exists since sub-basin HO-9 lies downstream from sub-basins HO-2, HO-3, and HO-4. In order to prepare an accurate forecast for sub-basin HO-9, for example, all or some of the sub-basins upstream from HO-9 would have to be gaged; therefore it may be possible for multiple systems to share precipitation and stream flow gages.

Connecticut River Region:

Table 4 presents the benefits to costs analysis for a flood warning system for the Connecticut River Region. The Connecticut River Region includes the Deerfield, Westfield, Farmington, Connecticut, Millers and Chicopee River basins. In the Connecticut River Region, there are a total of 10 sub-basins having B/C ratios of greater than one when the sub-basins are independently examined. The following locations were identified as potential flood warning system candidates;

Location	Basin Code	Benefit/Cost Ratio
Cold River	DE-12	3.7
West Branch Westfield River	WE-38	8.3
Bradley Brook	WE-40	1.2
Little River	WE-42	58.0
Powdermill Brook	WE-44	4.6
Westfield River	WE-46	1.4
Broad Brook	CV-23	2.2
Mill River	CV-22	1.8
Millers River	MI-2	1.1
Upper Quaboag River	CP-32	2.2

There is great potential for sharing of hardware costs for a flood warning system between the described basins in the Westfield River basin and in the Connecticut River basin.

Central Region:

Table 5 presents the benefits to costs analysis for a flood warning system for the Central Region. The Central Region includes the Quinebaug, French, Nashua, Blackstone, Merrimack, Concord, and Shawsheen River basins. In the Central Region, there are a total of 4 sub-basins having B/C ratios of greater than one when the sub-basins are independently examined.

The following locations were identified as potential flood warning system candidates;

Location	Basin Code	Benefit/Cost Ratio
Quinebaug River	TH-1A	2.1
Mumford River	BL-65	3.8
Sudbury River	SU-17	15.3
Shawsheen River	ME-19	2.6

Coastal Region:

Table 6 presents the benefits to costs analysis for a flood warning system for the Coastal Region. The Coastal Region includes the Parker, Ipswich, North Coastal, Boston Harbor, South Coastal, Buzzards Bay, Taunton, Narragansett Bay and Mount Hope Bay Shore, and Ten Mile River Basins. In the Coastal Region, there are a total of 6 sub-basins having B/C ratios of greater than one when the sub-basins are independently examined. The following locations were identified as potential flood warning system candidates;

Location	Basin Code	Benefit/Cost Ratio
Ipswich River	IP-4	5.0
Saugus River	NS-7	4.3
Neponset River	NE-22	26.8
Weweantic River	BB-42	3.1
Three mile River	TA-56	1.8
Ten Mile River	NB-60	9.9

VIII. CONCLUSIONS

This report examines the existing flood warning and response capabilities provided to the Commonwealth of Massachusetts by the NWS and discusses the role of ALERT and the NWS's IFLOWS flood warning and response systems in improving the current level of warning coverage. The study identifies the locations where the NWS provides specific flood forecasts within the Commonwealth and discusses the more generalized warnings and watches prepared for the remaining areas. The study determined that the level of warning provided by the NWS meets the public safety concerns for the major flood prone areas of the Commonwealth. Furthermore, the report did not identify any gaps in precipitation or stream flow data which impacts on the preparation or the accuracy of the forecasts prepared by the NWS.

The current NWS coverage combined with the existing communication system established by the Massachusetts Emergency Management Agency (MEMA) would indicate that the implementation of a statewide system such as IFLOWS is not necessary. However, this flood warning assessment report does identify numerous locations within the Commonwealth which could benefit from the implementation of additional warning capabilities. These locations are typically concentrated areas of development along rivers or streams with small drainage areas. These locations receive some public safety benefit from the warnings and watches issued by the NWS for the large precipitation events, but can still experience flooding from more concentrated storms with little advanced warning. The advanced warning provided by the normal NWS procedures allows for little reaction time beyond the evacuation of the flood prone areas. These locations appear to be promising candidates for local flood warning systems to both increase the reaction time available to evacuate the flood plains and to incorporate flood damage reduction measures to reduce flood losses. It should be stressed, however, that flood warning in itself is not a complete solution to flooding, only a means of reducing the potential risk to people and property.

If the Commonwealth of Massachusetts or the communities in the locations identified in this report wish to pursue the implementation of ALERT systems, several important issues must be stressed. The first is the determination of the appropriate type of flood warning system. If the principal objective of the system is the protection and safe evacuation of flood prone areas, then a simple alarm type system may be sufficient. Some limited flood damage reduction may be possible with this type of system. These systems are generally inexpensive and do not require extensive training to operate after their initial implementation and calibration. The NWS and other Federal and state agencies may be able to provide technical support to lay out the system and to set the proper rainfall or stream flow threshold levels. If the goal of the system is a more complete reduction in flood damages, then a more comprehensive system with internal flood forecasting capabilities may be required. The removal of building contents or the implementation of flood proofing measures requires a forecast of the expected flood stage and its time of arrival. This requires internal forecasting software which interrogates the gages and performs hydraulic routing calculations. The software must have access to information which defines the antecedent conditions and requires several years of data to properly calibrate the model. This type of system would be more costly and would require a trained operator. Furthermore, this type of forecast system would receive little support from the Federal agencies beyond what was been previously discussed. Since the NWS has yet to develop an automated flood forecasting model for the Northeast, the user would have to rely on private vendor software which has not been tested in this region of the country.

The second important issue which should be addressed is the preparation of a comprehensive emergency response plan. The emergency response plan should provide a link between the public affected by a flooding event and the flood warning system. The plan should be prepared in conjunction with the implementation of the flood warning system and should completely address the procedures, responsibilities, and actions of the community in disseminating the warning information to the affected community and identifying the response measures which are the responsibility of the local government. The response plan should also address the post storm activities. The preparation of a preparedness plan is appropriately a local responsibility and should be considered a significant undertaking. Programs are available from Federal agencies such as the NWS and the Corps of Engineers to assist in the preparation and content of the plans.

The final and perhaps the most overlooked issue associated with flood warning systems is the long term support and maintenance of the systems. A mechanism needs to be implemented at a state or regional level to protect the initial investment in the system features and maintain an educated user community dedicated to the long term success of the systems. This type of commitment may be difficult to expect from an individual community. A mechanism similar to the ASERT/ALERT program adopted by the State of Connecticut would be a good model to follow.

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TABLE 3 – BENEFITS VERSUS COSTS OF FLOOD WARNING SYSTEMS – BERKSHIRE REGION

(Costs based on individual basin analysis and do not include potential multi-basin savings)

Basin No.	River Basin	Basin Code	Watershed	Upstream Watersheds	AAD(1) ($1,000)	Drainage Area (sq mi)	NWS Forecast	No. of Gages(2)	Warning Time(3) (hrs)	Reduction in Damage (%)	Reduction AAD ($1000)	Initial Cost ($1000)	Avg. Annual Cost ($1000)	B/C Ratio
1a	HUDSON (Hoosic)	HU-1	Hoosic R		(4)	47	No	–	–	–	–	–	–	–
		HU-3	Hudson Br		14	(5)	No	–	–	–	–	–	–	–
		HU-4	Green R		321	43	No	3	4.5	10	33.6	23	6.4	5.3
		HU-2	Hoosic R	HU-1,3,4	17	206	No	5	10.8	20	3.5	31	8.8	0.4
2	HOUSATONIC	HO-1	W Br Housatonic R		60	37	No	3	4.1	10	5.8	23	6.4	0.9
		HO-2	SW Br Housatonic R		131	24	No	3	3.1	8	9.9	23	6.4	1.6
		HO-3	E Br Housatonic R		56	53	No	3	5.1	12	6.5	23	6.4	1.0
		HO-4	E Br Housatonic R	HO-3	387	71	No	4	6.1	13	51.6	27	7.6	6.8
		HO-5	Housatonic R	HO-1 thru 4	(4)	167	No	–	–	–	–	–	–	–
		HO-7	Washington Mtn Br		15	(5)	No	–	–	–	–	–	–	–
		HO-8	Hop Br		(4)	23	No	–	–	–	–	–	–	–
		HO-6	Housatonic R	HO-1 thru 5,7,8	195	278	Yes	6	12.5	(6)	–	36	10.0	–
		HO-10	Williams R		(4)	43	No	–	–	–	–	–	–	–
		HO-9	Housatonic R	HO-1 thru 8,10	60	360	No	6	14.2	24	14.6	36	10.0	1.5
		HO-11	Green R		19	53	No	3	5.1	12	2.2	23	6.4	0.3
		HO-13	Hubbard Br		(4)	50	No	–	–	–	–	–	–	–
		HO-12	Housatonic R	HO-1 thru 11,13	(4)	535	No	–	–	–	–	–	–	–
		HO-14	Konkapot R		39	58	No	3	5.4	12	4.7	23	6.4	0.7

(1) All values in 1992 dollars.
(2) Number of gages = (drainage area)**0.31 with minimum of 3 gages
(3) Warning time = 1.29 * (drainage area)**0.43 – 2.0 (hours)
(4) Average annual damages < $10,000 . No benefits or costs were calculated.
(5) Drainage area < 10 square miles. No benefits or costs were calculated.
(6) Reduction in damages not calculated. The reduction in damages of the NWS flood forecast currently prepared has not been evaluated.

TABLE 4 - BENEFITS VERSUS COSTS OF FLOOD WARNING SYSTEMS - CONNECTICUT RIVER REGION

(Costs based on individual basin analysis and do not include potential multi-basin savings)

Basin No.	River Basin	Basin Code	Watershed	Upstream Watersheds	AAD(1) ($1,000)	Drainage Area (sq mi)	NWS Forecast	No. of Gages(2)	Warning Time(3) (hrs)	Reduction in Damage (%)	Reduction AAD ($1000)	Initial Cost ($1000)	Avg. Annual Cost ($1000)	B/C Ratio
3	DEERFIELD	DE-11	Deerfield R		(4)	312	No	-	-	-	-	-	-	-
		DE-12	Cold R		266	32	No	3	3.7	9	23.8	23	6.4	3.7
		DE-13	Deerfield R	DE-11,12	29	400	No	6	15.0	25	7.3	36	10.0	0.7
		DE-14	Classen Br		23	21	No	3	2.8	7	1.6	23	6.4	0.3
		DE-15	Deerfield R	DE-11 thru 14	39	498	No	7	16.6	26	10.3	40	11.2	0.9
		DE-16	Deerfield R	DE-11 thru 15	23	569	No	7	17.7	27	6.2	40	11.2	0.6
		DE-10	Deerfield R	DE-11 thru 16	16	662	No	8	19.1	28	4.4	44	12.4	0.4
4	WESTFIELD	WE-36	Westfield R		(4)	170	No	-	-	-	-	-	-	-
		WE-37	Mid Br Westfield R		(4)	54	No	-	-	-	-	-	-	-
		WE-38	W Br Westfield R		411	98	No	4	7.3	15	63.2	27	7.6	8.3
		WE-40	Bradley Br		165	11	No	3	1.6	5	7.4	23	6.4	1.2
		WE-41	Russell Br		(4)	(5)	No	-	-	-	-	-	-	-
		WE-43	Munn Br		19	22	No	3	2.9	7	1.4	23	6.4	0.2
		WE-42	Little R	WE-43	3058	84	No	4	6.7	14	440.0	27	7.6	58.0
		WE-44	Powdermill Br		526	19	No	4	2.6	7	34.6	27	7.6	4.6
		WE-39	Westfield R	WE-36,37,38,40-44	2074	497	Yes	7	16.6	(7)	-	40	11.2	-
		WE-45	Great Br		(4)	25	No	-	-	-	-	-	-	-
		WE-46	Westfield R	WE-36 thru 45	60	517	No	7	16.9	27	15.9	40	11.2	1.4
5	FARMINGTON	FA-53	W Br Farmington R		(4)	27	No	-	-	-	-	-	-	-
		FA-54	W Br Farmington R	FA-53	(4)	59	No	-	-	-	-	-	-	-
		FA-55	Clam R		45	32	No	3	3.7	9	4.0	23	6.4	0.6
		FA-56	W Br Farmington R	FA-53,54,55	(4)	103	No	-	-	-	-	-	-	-
6	CONNECTICUT	NC-8	Connecticut R		(6)	6765	No	-	-	-	-	-	-	-
		NC-9	Falls R		(4)	35	No	-	-	-	-	-	-	-
		CV-18	Sawmill R		(4)	32	No	-	-	-	-	-	-	-
		CV-17	Connecticut R	NC-8,9,CV-18	(6)	7865	Yes	-	-	-	-	-	-	-
		CV-21	Fort R		(4)	59	No	-	-	-	-	-	-	-
		CV-19/20	Connecticut R	NC-8,9,CV-17,18	(6)	8030	Yes	-	-	-	-	-	-	-
		CV-25	Bachelor Br		(4)	38	No	-	-	-	-	-	-	-
		CV-23	Broad Br		290	12	No	3	1.8	5	14.0	23	6.4	2.2
		CV-24	Manhan R	CV-23	34	86	No	4	6.8	15	4.9	27	7.6	0.7
		CV-22	Mill R	CV-23,24	93	60	No	3	5.5	12	11.5	23	6.4	1.8
		CV-26	Connecticut R	NC-8,9,CV-17-25	(6)	8309	Yes	-	-	-	-	-	-	-
		SC-47	Mill R		(4)	34	No	-	-	-	-	-	-	-
		SC-48	Connecticut R	NC-8,9,CV-17-26	(6)	9640	Yes	-	-	-	-	-	-	-

(CONTINUED ON NEXT PAGE)

TABLE 4 (CONTINUED) - BENEFITS VERSUS COSTS OF FLOOD WARNING SYSTEMS - CONNECTICUT RIVER REGION

(Costs based on individual basin analysis and do not include potential multi-basin savings)

Basin No.	River Basin	Basin Code	Watershed	Upstream Watersheds	AAD(1) ($1,000)	Drainage Area (sq mi)	NWS Forecast	No. of Gages(2)	Warning Time(3) (hrs)	Reduction in Damage (%)	Reduction AAD ($1000)	Initial Cost ($1000)	Avg. Annual Cost ($1000)	B/C Ratio
7	MILLERS	MI-1	Otter R		(4)	62	No	-	-	-	-	-	-	-
		MI-3	Tully R		(4)	77	No	-	-	-	-	-	-	-
		MI-2	Millers R	MI-1,3	50	279	No	6	12.5	23	11.3	36	10.0	1.1
		MI-4	Millers R	MI-1,2,3	(4)	330	No	-	-	-	-	-	-	-
		MI-5	Millers R	MI-1 thru 4	(4)	375	No	-	-	-	-	-	-	-
		MI-6	Millers R	MI-1 thru 5	(4)	392	No	-	-	-	-	-	-	-
8	CHICOPEE	CP-29	Ware R		(4)	154	No	-	-	-	-	-	-	-
		CP-30	Danforth Br		33	(5)	No	-	-	-	-	-	-	-
		CP-31	Ware R	CP-29,30	(4)	218	No	-	-	-	-	-	-	-
		CP-27	Quabbin Res		(4)	187	No	-	-	-	-	-	-	-
		CP-32	Upper Quaboag R		106	148	No	5	9.1	18	19.3	31	8.8	2.2
		CP-33	Lower Quaboag R	CP-32	19	214	No	5	11.0	21	3.9	31	8.8	0.4
		CP-28	Ware R	CP-27,29 thru 33	23	664	No	8	19.1	28	6.4	44	12.4	0.5
		CP-34	Twelvemile Br		(4)	15	No	-	-	-	-	-	-	-
		CP-35	Chicopee R	CP-27 thru 34	19	721	Yes	8	19.9	(7)	-	44	12.4	-

(1) All values in 1992 dollars.
(2) Number of gages = (drainage area)**0.31 with minimum of 3 gages
(3) Warning time = 1.29 * (drainage area)**0.43 - 2.0 (hours)
(4) Average annual damages < $10,000 . No benefits or costs were calculated.
(5) Drainage area < 10 square miles. No benefits or costs were calculated.
(6) AAD's unavailable on the mainstem Connecticut River.
(7) Reduction in damages not calculated. The reduction in damages of the NWS flood forecast currently prepared has not been evaluated.

TABLE 5 - BENEFITS VERSUS COSTS OF FLOOD WARNING SYSTEMS - CENTRAL REGION

(Costs based on individual basin analysis and do not include potential multi-basin savings)

Basin No.	River Basin	Basin Code	Watershed	Upstream Watersheds	AAD(1) ($1,000)	Drainage Area (sq mi)	NWS Forecast	No. of Gages(2)	Warning Time(3) (hrs)	Reduction in Damage (%)	Reduction AAD ($1000)	Initial Cost ($1000)	Avg. Annual Cost ($1000)	B/C Ratio
9	QUINEBAUG	TH-1A	Quinebaug R		98	156	No	5	9.3	19	18.2	31	8.8	2.1
10	FRENCH	TH-2	French R		(4)	85	No	-	-	-	-	-	-	-
11	NASHUA	NA-2	N Br Nashua R		(6)	57	No	-	-	-	-	-	-	-
		NA-3	N Br Nashua R	NA-2	(6)	99	No	-	-	-	-	-	-	-
		NA-4	N Br Nashua R	NA-2,3	6385	131	Yes	4	8.5	(9)	-	27	7.6	-
		NA-5	Quinapoxet R		(4)	55	No	-	-	-	-	-	-	-
		NA-6	S Br Nashua R	NA-5	(4)	131	No	-	-	-	-	-	-	-
		NA-8	Catacoonamug Br		14	21	No	3	2.8	7	1.0	23	6.4	0.2
		NA-7	Nashua R	NA-2 thru 6,8	23	205	No	5	10.7	20	4.7	31	8.8	0.5
		NA-9	Mulpus Br		(4)	16	No	-	-	-	-	-	-	-
		NA-10	Squannacook R		27	57	No	3	5.3	12	3.2	23	6.4	0.5
		NA-11	Nashua R	NA-2 thru 10	33	396	Yes	6	14.9	(9)	-	36	10.0	-
12	BLACKSTONE	BL-61	Ramshorn Br		33	52	No	3	5.1	12	3.8	23	6.4	0.6
		BL-62	Blackstone R	BL-61	(4)	97	No	-	-	-	-	-	-	-
		BL-63	Quinsigamond R		43	39	No	3	4.2	10	4.3	23	6.4	0.7
		BL-65	Mumford R		241	57	No	4	5.3	12	29.0	27	7.6	3.8
		BL-66	West R		(4)	37	No	-	-	-	-	-	-	-
		BL-64	Blackstone R	BL-61,62,63,65,66	113	330	Yes	6	13.6	(9)	-	36	10.0	-
		BL-67	Mill R		(4)	35	No	-	-	-	-	-	-	-
13	MERRIMACK	ME-13	Merrimack R Valley		(7)	?	No	-	-	-	-	-	-	-
		ME-14	Stony Br		(4)	46	No	-	-	-	-	-	-	-
		ME-15	Merrimack R Valley	ME-13,14	133	4672	Yes	(8)	-	-	-	-	-	-
		ME-20	Merrimack R Valley	ME-13 thru 15	(7)	4900	Yes	-	-	-	-	-	-	-
		ME-21	Merrimack R Valley	ME-13 thru 15,21	(7)	4980	No	-	-	-	-	-	-	-
		ME-12	Cow Pond Br		(4)	22	No	-	-	-	-	-	-	-

(CONTINUED ON NEXT PAGE)

TABLE 5 (CONTINUED) - BENEFITS VERSUS COSTS OF FLOOD WARNING SYSTEMS - CENTRAL REGION

(Costs based on individual basin analysis and do not include potential multi-basin savings)

Basin No.	River Basin	Basin Code	Watershed	Upstream Watersheds	AAD(1) ($1,000)	Drainage Area (sq mi)	NWS Forecast	No. of Gages(2)	Warning Time(3) (hrs)	Reduction in Damage (%)	Reduction AAD ($1000)	Initial Cost ($1000)	Avg. Annual Cost ($1000)	B/C Ratio
14a,b	CONCORD	AS-17	Assabet R		13	176	Yes	5	9.9	(9)	-	31	8.8	-
	(Concord and	SU-16	Baiting Br		(4)	(5)	No	-	-	-	-	-	-	-
	Concord &	SU-17	Sudbury R	SU-16	709	166	No	5	9.6	19	134.5	31	8.8	15.3
	Sudbury)	CO-17	Concord R	AS-17,SU-16,17	93	405	Yes	6	15.1	(9)	-	36	10.0	-
		ME-18	River Meadow Br		(4)	27	No	-	-	-	-	-	-	-
15	SHAWSHEEN	ME-19	Shawsheen R		145	74	No	4	6.2	14	19.7	27	7.6	2.6

(1) All values in 1992 dollars.
(2) Number of gages = (drainage area)**0.31 with minimum of 3 gages
(3) Warning time = 1.29 * (drainage area)**0.43 - 2.0 (hours)
(4) Average annual damages < $10,000 . No benefits or costs were calculated.
(5) Drainage area < 10 square miles. No benefits or costs were calculated.
(6) Average annual damages for these reaches included in average annual damage for NA-4.
(7) AAD's unavailable on the mainstem Merrimack River.
(8) Drainage area is too large for the type of ALERT system analyzed.
(9) Reduction in damages not calculated. The reduction in damages of the NWS flood forecast currently prepared has not been evaluated.

TABLE 6 – BENEFITS VERSUS COSTS OF FLOOD WARNING SYSTEMS – COASTAL REGION

(Costs based on individual basin analysis, not on multi-basin analysis)

Basin No.	River Basin	Basin Code	Watershed	Upstream Watersheds	AAD(1) ($1,000)	Drainage Area (sq mi)	NWS Forecast	No. of Gages(2)	Warning Time(3) (hrs)	Reduction in Damage (%)	Reduction AAD ($1000)	Initial Cost ($1000)	Avg. Annual Cost ($1000)	B/C Ratio
16	PARKER	PA-3	Parker R		(4)	24	No	–	–	–	–	–	–	–
17	IPSWICH	IP-4	Ipswich R		235	156	No	5	9.3	19	43.6	31	8.8	5.0
18	NORTH COASTAL	NS-7	Saugus R		372	23	No	3	3.0	7	27.5	23	6.4	4.3
19a	BOSTON HARBOR (Mystic)	NS-8	Mystic R		40	62	No	4	5.6	13	5.0	27	7.6	0.7
19b	BOSTON HARBOR (Neponset)	NE-17	Neponset R		(4)	24	No	–	–	–	–	–	–	–
		NE-18	Diamnd–Traphole Br		154	(5)	No	–	–	–	–	–	–	–
		NE-19	E Br Neponset R		16	33	No	3	3.8	9	1.5	23	6.4	0.2
		NE-20	Neponset R	NE-17 thru 19	70	91	Yes	4	7.0	(6)	–	27	7.6	–
		NE-21	Pine Tree Br		(4)	(5)	No	–	–	–	–	–	–	–
		NE-22	Neponset R	NE-17 thru 21	1211	121	No	4	8.1	17	203.3	27	7.6	26.8
21a	SOUTH COASTAL (North & South Rivers)	SS-27	North R		(4)	81	No	–	–	–	–	–	–	–
24	BUZZARDS BAY	BB-42	Weweantic R		182	45	No	3	4.6	11	19.5	23	6.4	3.1
		BB-45	Acushnet R		79	18	No	3	2.5	6	5.0	23	6.4	0.8
25	TAUNTON	TA-49	Shumatuscacant R		(4)	32	No	–	–	–	–	–	–	–
		TA-48	Matfield R	TA-49	50	80	No	4	6.5	14	7.0	27	7.6	0.9
		TA-47	Town R		(4)	60	No	–	–	–	–	–	–	–
		TA-50	Winnetuxet R		(4)	37	No	–	–	–	–	–	–	–
		TA-51	Taunton R	TA-47 thru 50	(4)	199	No	–	–	–	–	–	–	–
		TA-53	Nemasket R		(4)	70	No	–	–	–	–	–	–	–
		TA-52	Taunton R	TA-47 thru 51,53	21	314	No	6	13.3	23	4.9	36	10.0	0.5
		TA-54	Mill R		14	44	No	3	4.6	11	1.5	23	6.4	0.2
		TA-55	Rumford R		(4)	66	No	–	–	–	–	–	–	–
		TA-56	Threemile R	TA-55	97	84	No	4	6.7	14	14.0	27	7.6	1.8
		TA-57	Taunton R	TA-47 thru 56	(4)	481	No	–	–	–	–	–	–	–
		TA-58	Assonet R		(4)	35	No	–	–	–	–	–	–	–

(CONTINUED ON NEXT PAGE)

TABLE 6 (CONTINUED) - BENEFITS VERSUS COSTS OF FLOOD WARNING SYSTEMS - COASTAL REGION

(Costs based on individual basin analysis, not on multi-basin analysis)

Basin No.	River Basin	Basin Code	Watershed	Upstream Watersheds	AAD(1) ($1,000)	Drainage Area (sq mi)	NWS Forecast	No. of Gages(2)	Warning Time(3) (hrs)	Reduction in Damage (%)	Reduction AAD ($1000)	Initial Cost ($1000)	Avg. Annual Cost ($1000)	B/C Ratio
26	NARR BAY & MT.	NB-59	Palmer R		(4)	58	No	-	-	-	-	-	-	-
	HOPE BAY SHORE	NB-71	Quequechan R		(4)	24	No	-	-	-	-	-	-	-
		NB-72	Cole R		(4)	47	No	-	-	-	-	-	-	-
27	TEN MILE	NB-60	Ten Mile R		762	28	No	3	3.4	8	63.3	23	6.4	9.9

(1) All values in 1992 dollars.
(2) Number of gages = (drainage area)**0.31 with minimum of 3 gages
(3) Warning time = 1.29 * (drainage area)**0.43 - 2.0 (hours)
(4) Average annual damages < $10,000 . No benefits or costs were calculated.
(5) Drainage area < 10 square miles. No benefits or costs were calculated.
(6) Reduction in damages not calculated. The reduction in damages of the NWS flood forecast currently prepared has not been evaluated.

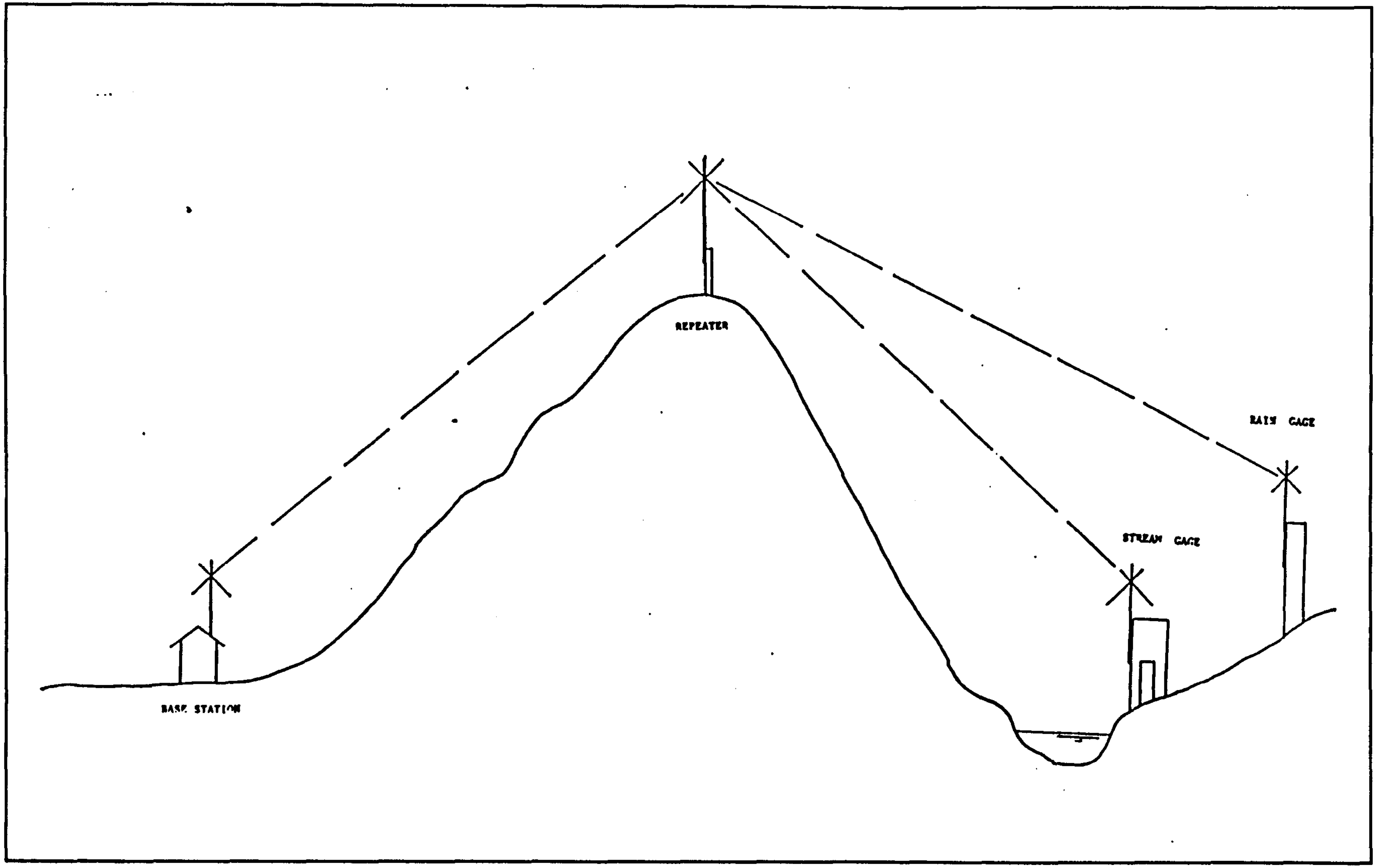


Figure 1 Typical ALERT Configuration

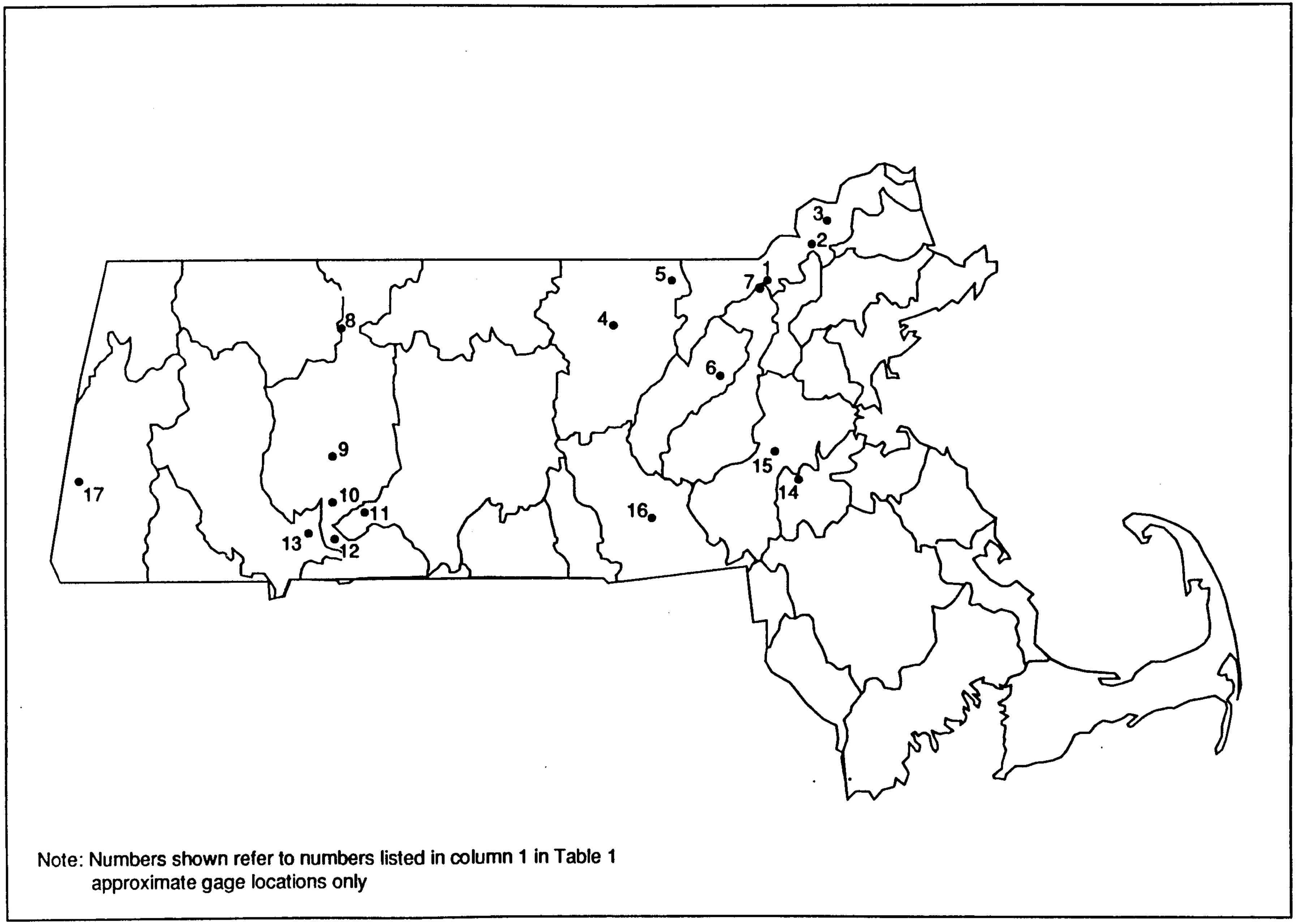
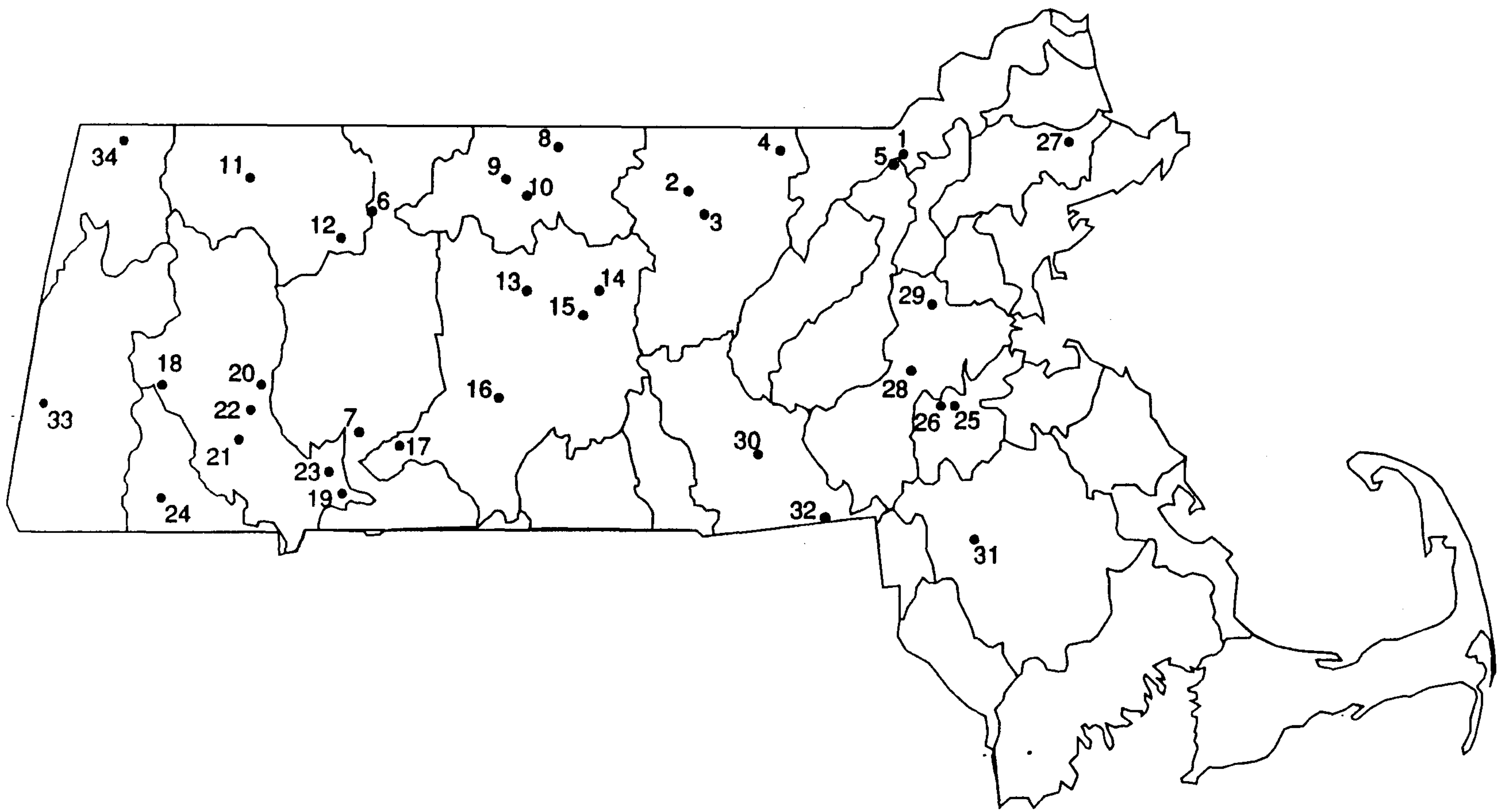
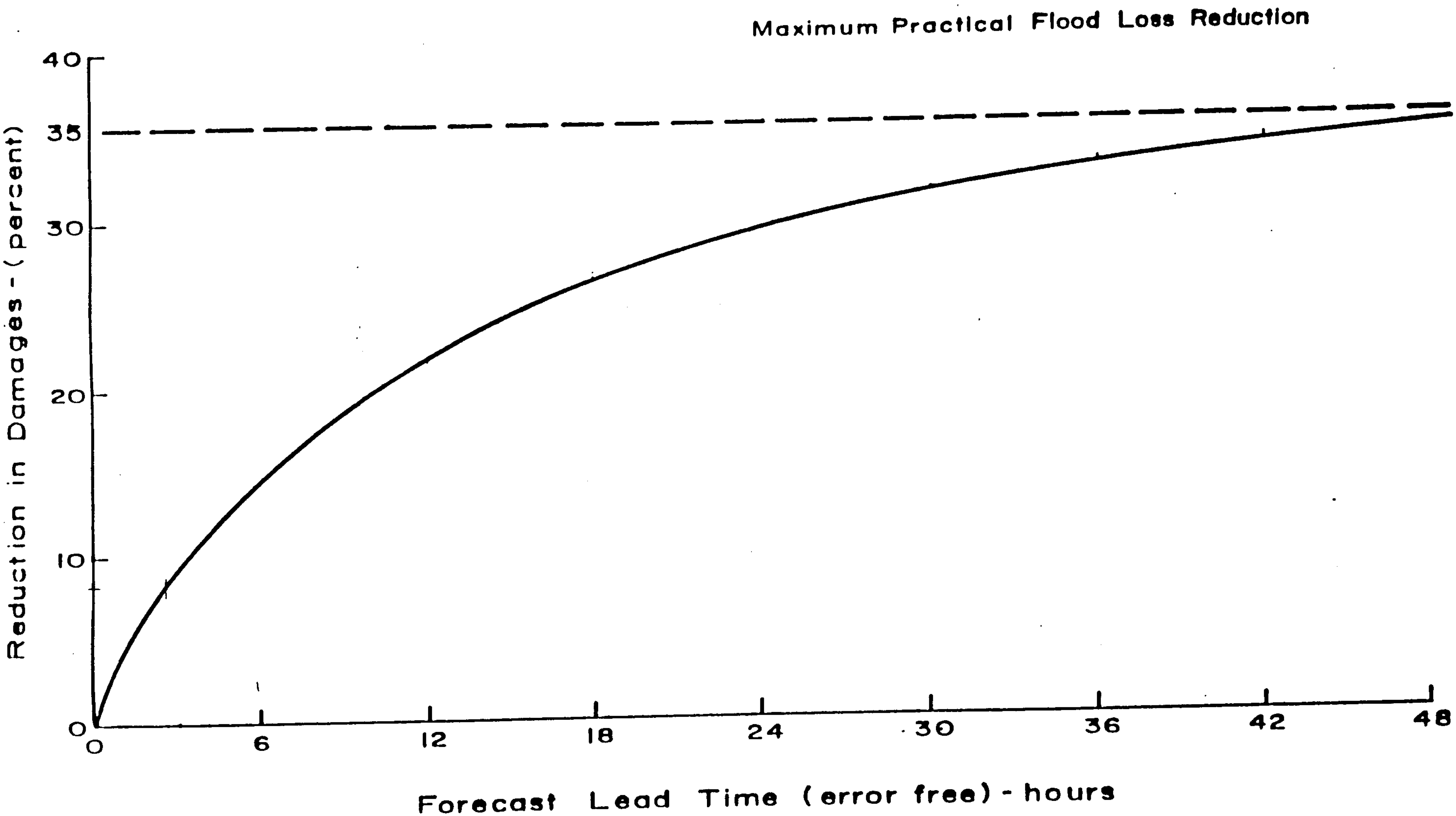


Figure 2 Locations of Stream Stage Forecast Points in Massachusetts



Note: Numbers shown refer to numbers listed in column 1 in Table 2
approximate gage locations only

Figure 3 Locations of Remote Reporting Stream Stage and Precipitation Gages in Massachusetts

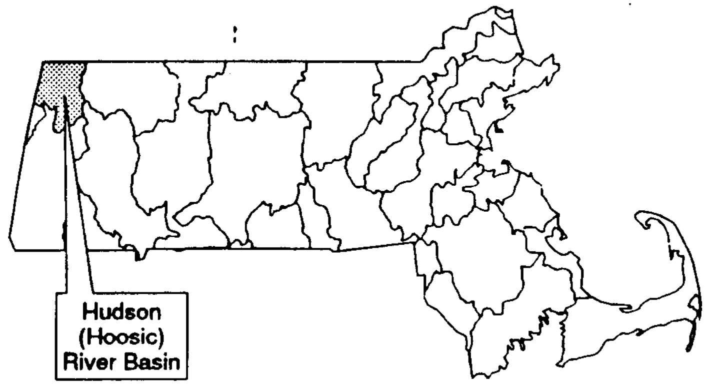


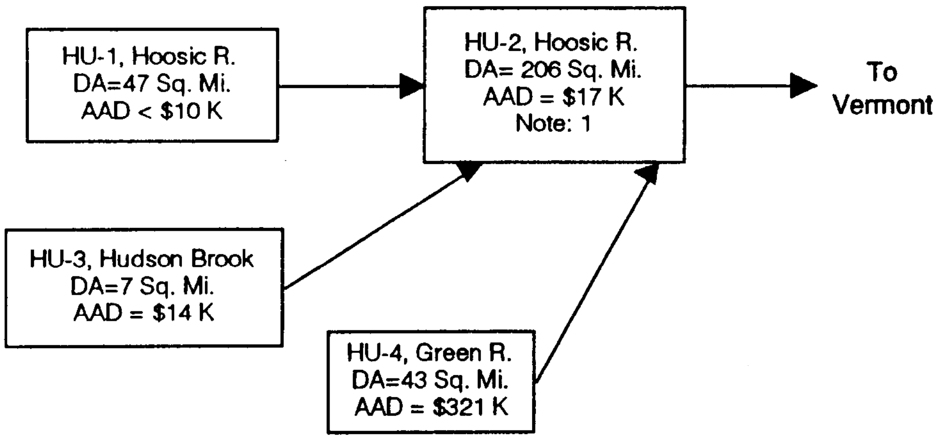
AFTER DAY (1970)

Figure 4 - Reduction in Total Flood Damages Versus Warning Time

Hudson (Hoosic) River Basin

Hydrologic Block Diagram
(Hydrologic Unit No. 02020003)

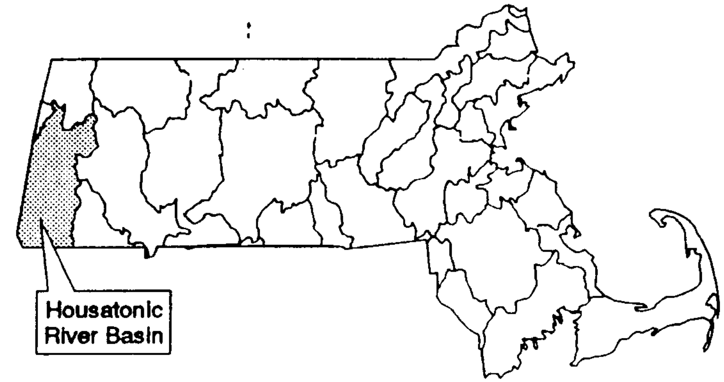


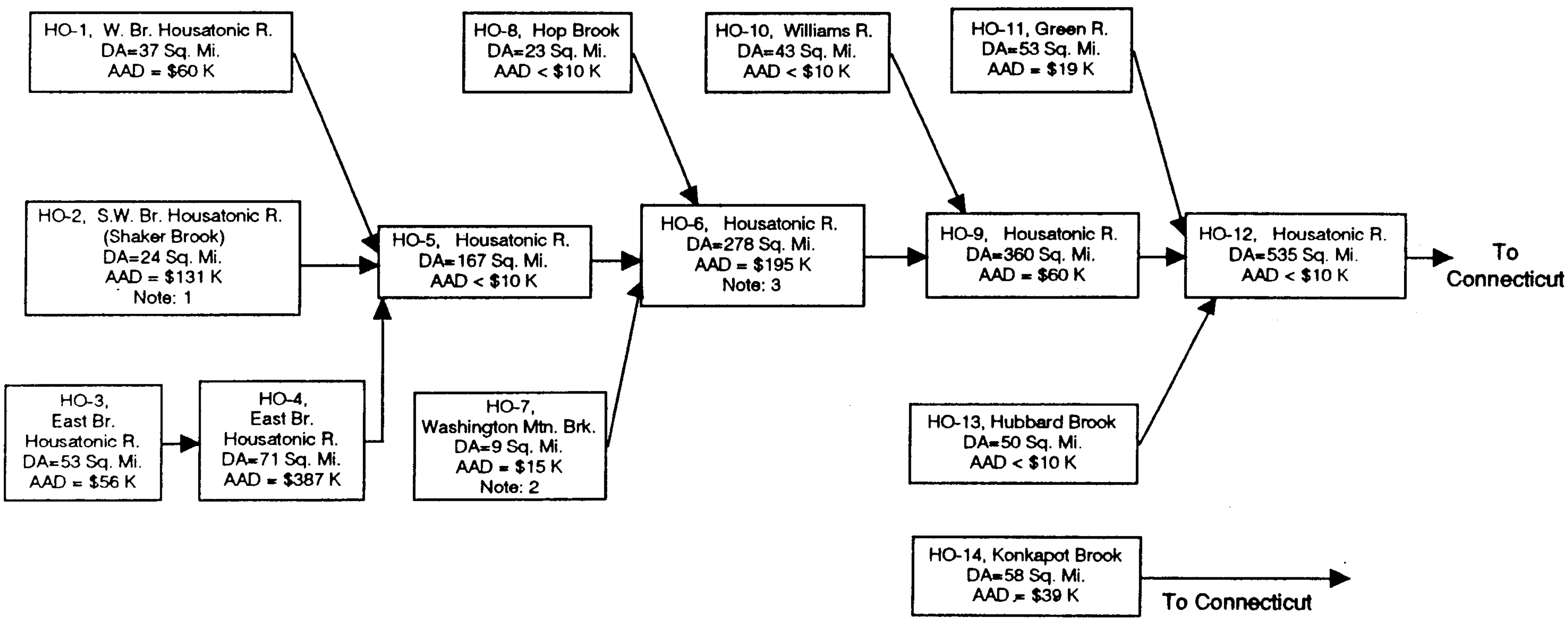


Notes: 1. USGS DCP, USGS Gage 01332500, Hoosic R. near Williamstown, DA= 126 Sq. Mi., (located just u/s confl. w/ HU-4)

Figure 5

Housatonic River Basin
Hydrologic Block Diagram
(Hydrologic Unit No. 01100005)



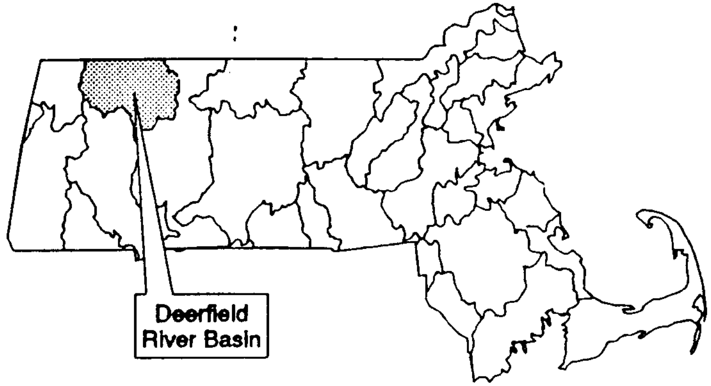


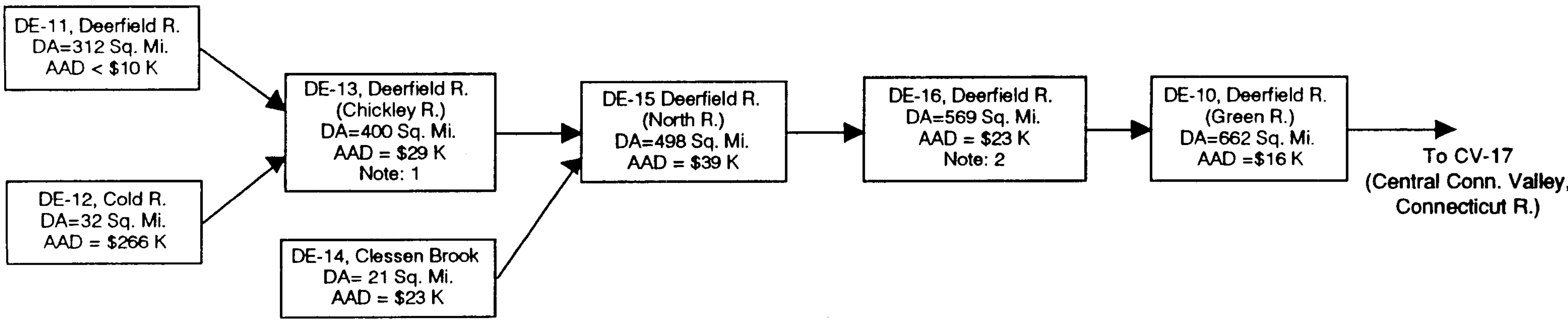
Notes:
1. The COE's Housatonic River Local Protection Project reduced damages to the value shown.
2. SCS's Washington Mountain Brook Project reduced damages to the value shown.
3. USGS Gage 01197500, Housatonic R. near Great Barrington, DA= 282 Sq. Mi., current NWS River Forecast location

Figure 6

Deerfield River Basin

Hydrologic Block Diagram
(Hydrologic Unit No. 01080203)



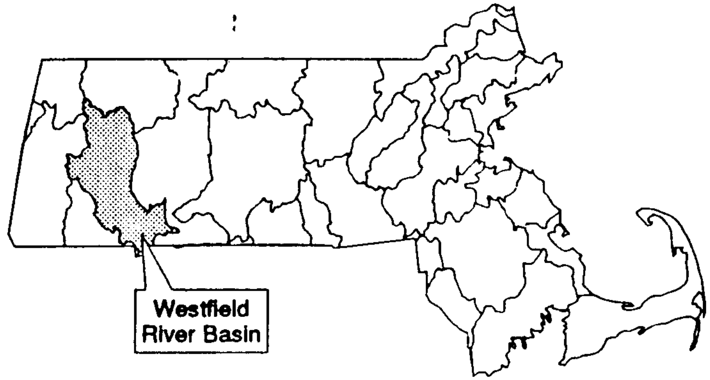


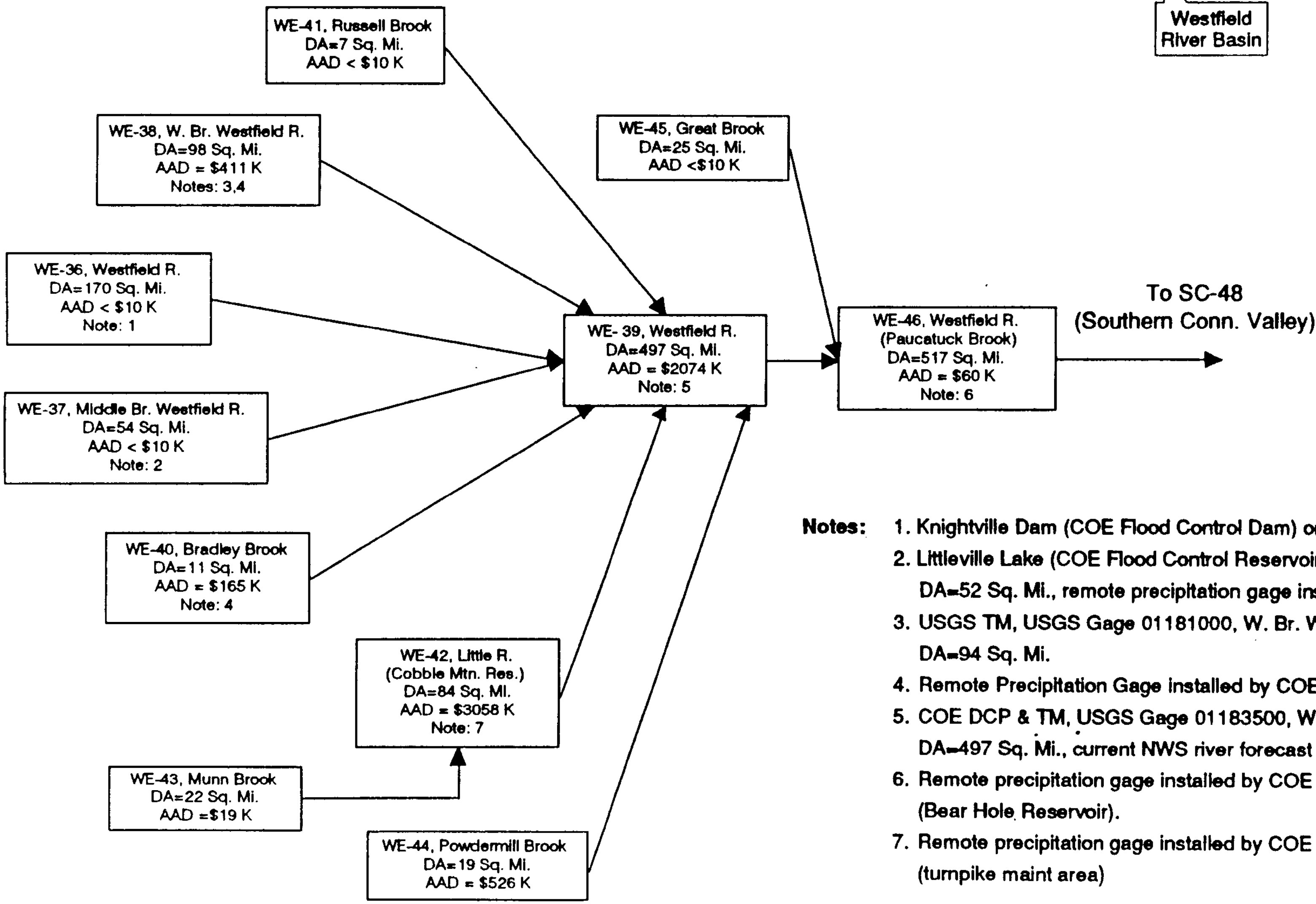
Notes: 1. USGS TM, USGS Gage 01168500, Deerfield R. at Charlemont, DA= 361 Sq. Mi.
2. COE DCP, USGS Gage 01170000, Deerfield River near West Deerfield, DA=557 Sq. Mi.

Figure 7

Westfield River Basin

Hydrologic Block Diagram
(Hydrologic Unit No. 01080206)



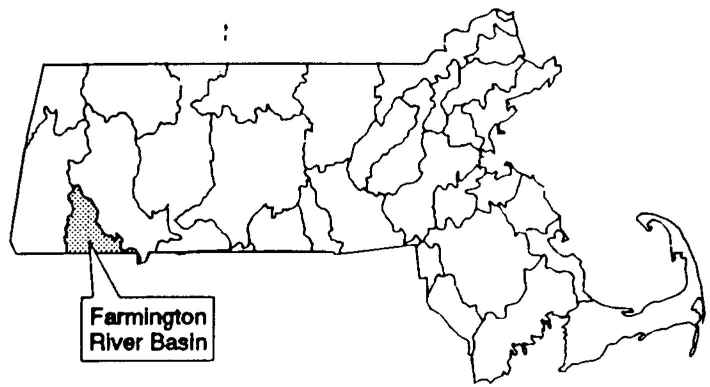


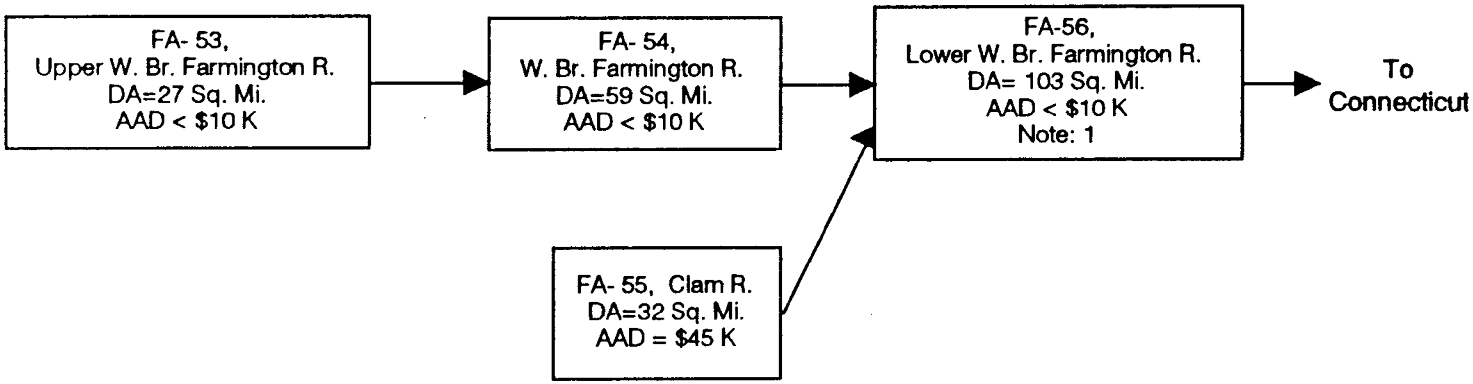
Notes:

1. Knightville Dam (COE Flood Control Dam) on the Westfield R., DA=162 Sq. Mi.
2. Littleville Lake (COE Flood Control Reservoir) on the Middle Br. Westfield R., DA=52 Sq. Mi., remote precipitation gage installed at the dam.
3. USGS TM, USGS Gage 01181000, W. Br. Westfield R. at Huntington, DA=94 Sq. Mi.
4. Remote Precipitation Gage installed by COE in Becket (turnpike maint. area).
5. COE DCP & TM, USGS Gage 01183500, Westfield R. near Westfield, DA=497 Sq. Mi., current NWS river forecast location.
6. Remote precipitation gage installed by COE in W. Springfield (Bear Hole Reservoir).
7. Remote precipitation gage installed by COE in Blanford (turnpike maint area)

Figure 8

Farmington River Basin
Hydrologic Block Diagram
(Hydrologic Unit No. 01080207)





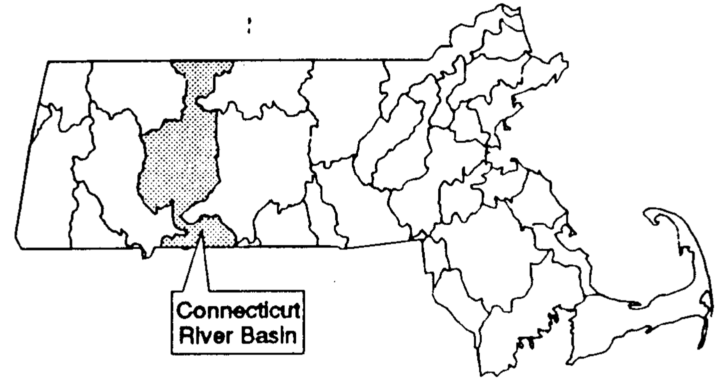
Notes: 1. USGS TM, USGS Gage 01185500, West Branch Farmington River near New Boston, DA= 92 Sq. Mi.

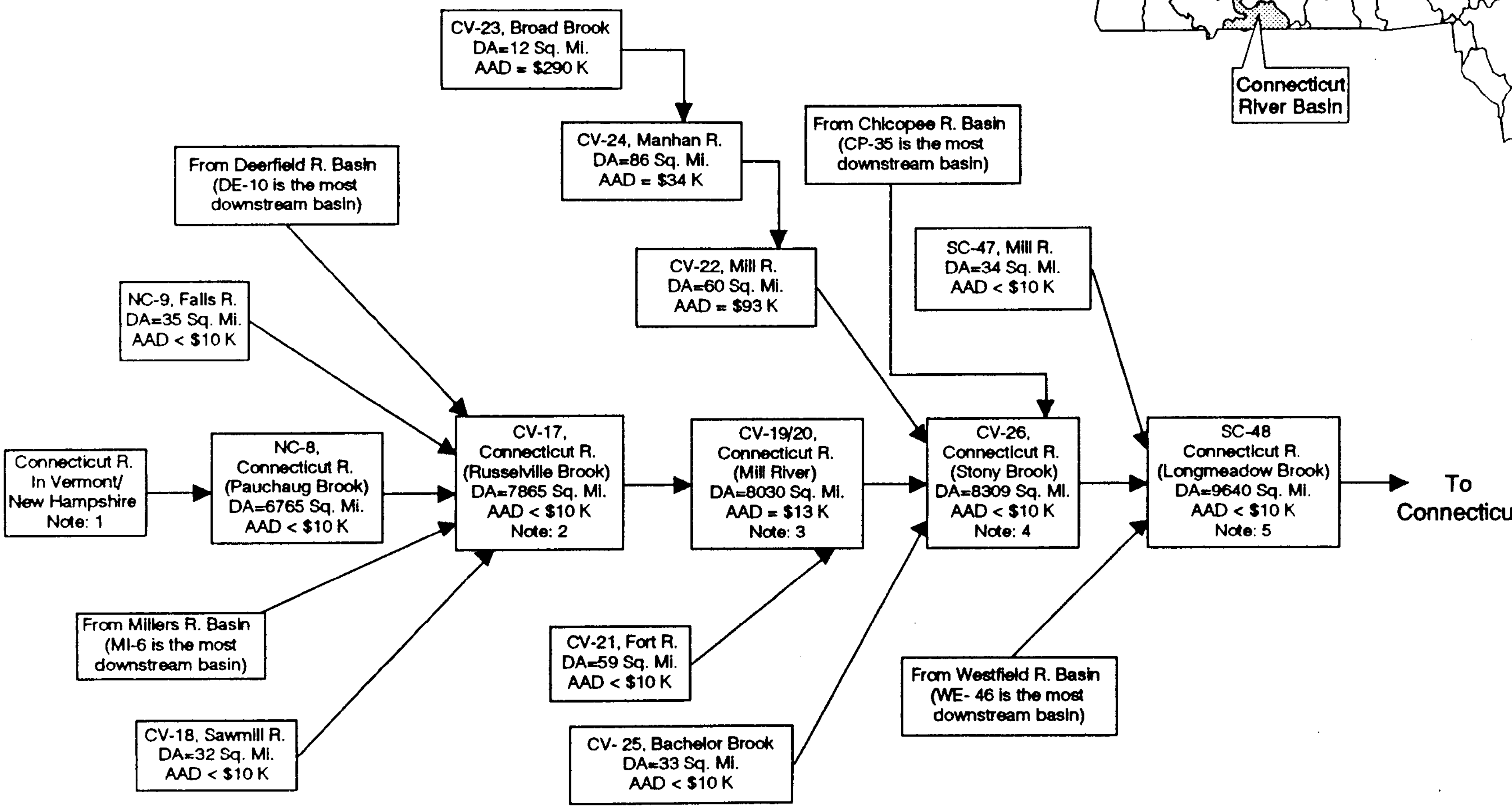
Figure 9

Connecticut River Basin *

Hydrologic Block Diagram

(Hydrologic Unit Nos. 01080201 and 01080205)





* Average annual damages unavailable on main stem

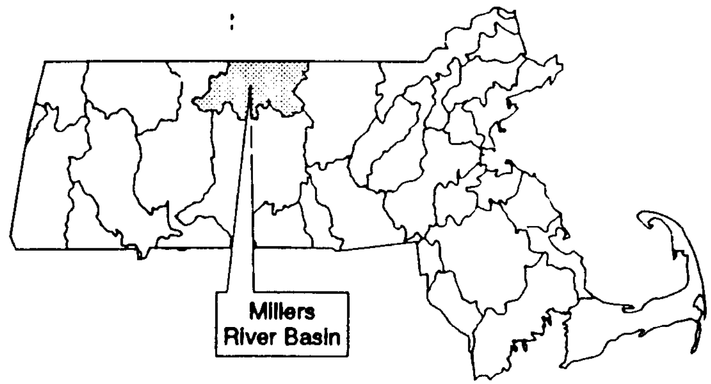
Notes:

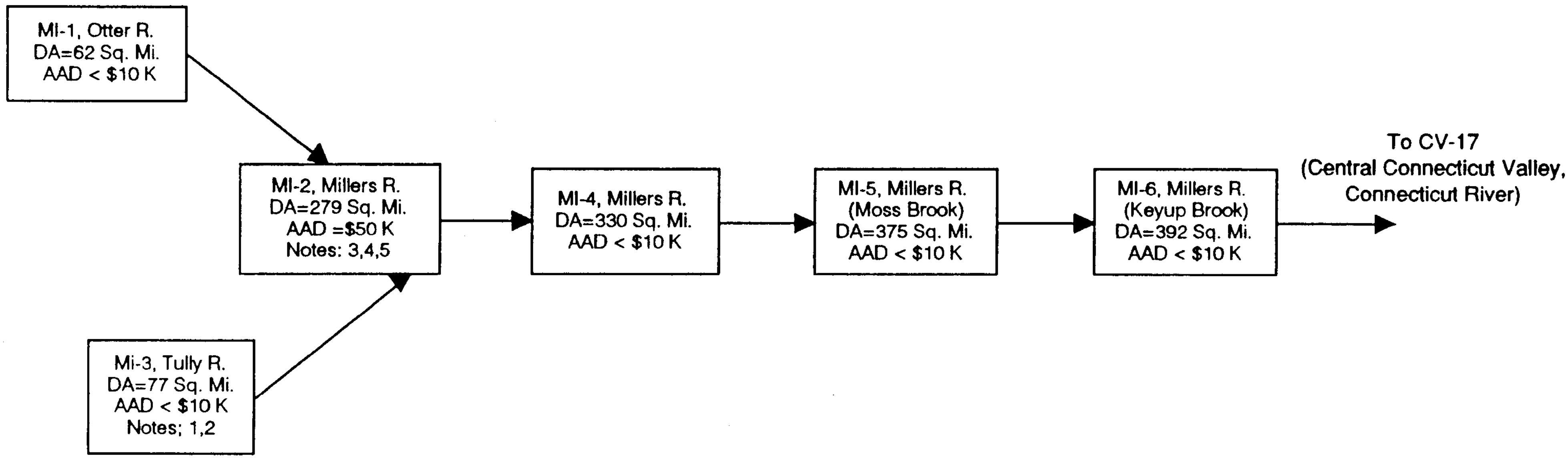
1. Several COE flood control reservoirs upstream.
2. COE DCP & TM, USGS Gage 01170500, Connecticut R. at Montague City, DA=7860 Sq. Mi., current NWS River forecast location.
3. Current NWS River forecast location, staff gage on Connecticut River at Holyoke in Northampton.
4. Power Co. TM, Connecticut River at Holyoke, DA= 8177 Sq. Mi., current NWS River forecast location.
5. Current NWS River forecast location, Connecticut River at Springfield, City of Springfield staff gage, DA= 9587 Sq. Mi.

Figure 10

Millers River Basin

Hydrologic Block Diagram
(Hydrologic Unit No. 01080202)



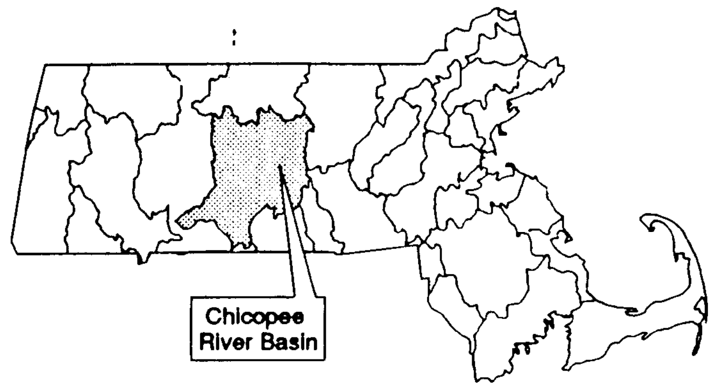


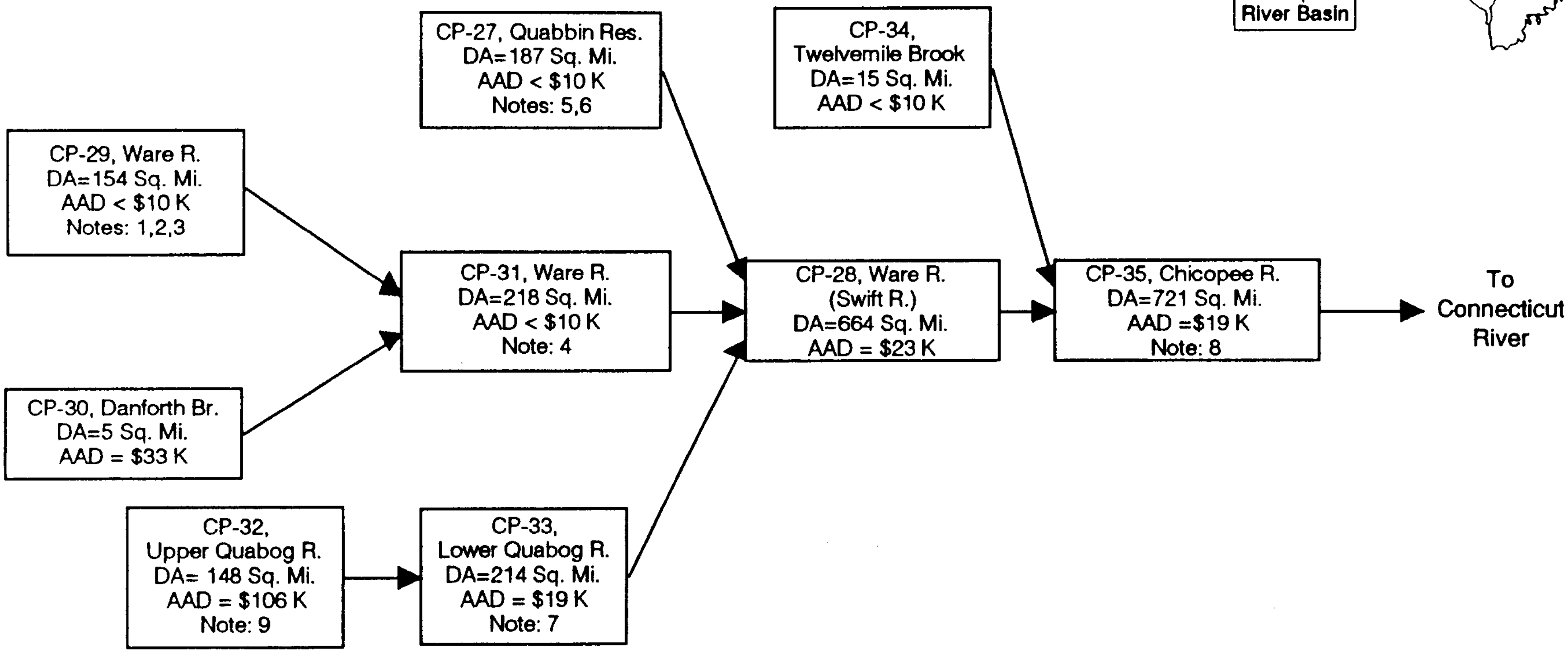
Notes:
1. Tully Lake (COE Flood control reservoir), on East Branch Tully River, DA= 50 Sq. Mi.
2. USGS TM, USGS Gage 01165000, East Branch Tully River near Athol, DA= 51 Sq. Mi. (downstream Tully Dam).
3. USGS DCP, USGS Gage 01162500, Priest Brook near Winchendon, DA= 19 Sq. Mi. (on small tributary).
4. Birch Hill Dam (COE Flood control dam) on Millers River, DA= 175 Sq. Mi.
5. COE DCP, COE Gage, Millers River in Athol, DA= 280 Sq. Mi.

Figure 11

Chicopee River Basin

Hydrologic Block Diagram
(Hydrologic Unit No. 01080204)





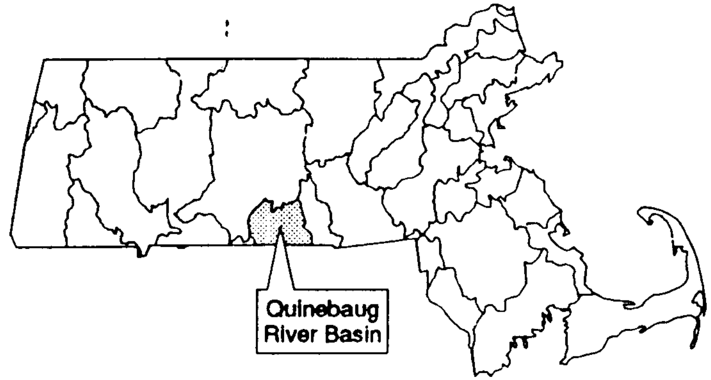
Notes:
1. Barre Falls Dam (COE Flood control reservoir) on the Ware River, DA= 55 Sq. Mi.
2. USGS TM, USGS Gage 01172500, Ware River near Barre (downstream Barre Falls Dam), DA= 55 Sq. Mi.
3. COE DCP, COE Gage, Ware River at Barre Plains, DA=115 Sq. Mi.
4. COE DCP, USGS Gage 01173500, Ware River at Gibbs Crossing, DA= 197 Sq. Mi.
5. USGS DCP, USGS Gage 01174500, East Branch Swift River at Hardwick, DA= 44 Sq. Mi.
6. Quabbin Reservoir (huge MWRA water supply reservoir), DA= 186 Sq. Mi.
7. Conant Brook Dam (COE Flood control reservoir) on small tributary to Chicopee Brook, DA= 8 Sq. Mi.
8. COE DCP & TM, USGS Gage 01177000, Chicopee River at Indian Orchard, DA= 688 Sq. Mi., current NWS River forecast location
9. SCS's Upper Quabog River Watershed Project reduced damages to the values shown.

Figure 12

Quinebaug River Basin

Hydrologic Block Diagram

(Hydrologic Unit No. 01100001)



TH-1a, Quinebaug R.
DA= 156 Sq. Mi.
AAD = $98 K
Notes: 1,2

→ To Connecticut

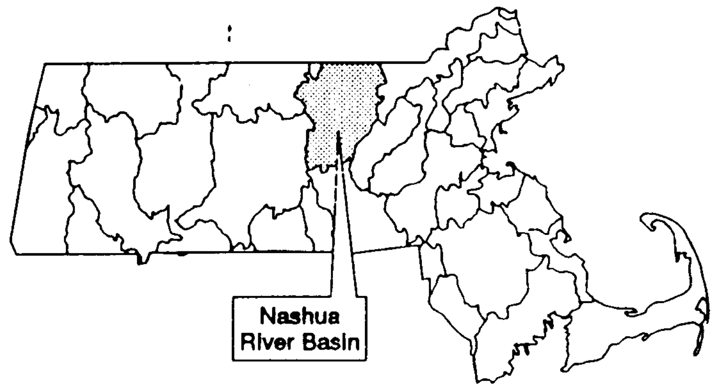
Notes: 1. East Brimfield Lake (COE Flood control reservoir) on Quinebaug River, DA= 68 Sq. Mi.
2. Westville Lake (COE Flood control reservoir) on Quinebaug River, DA= 100 Sq. Mi.

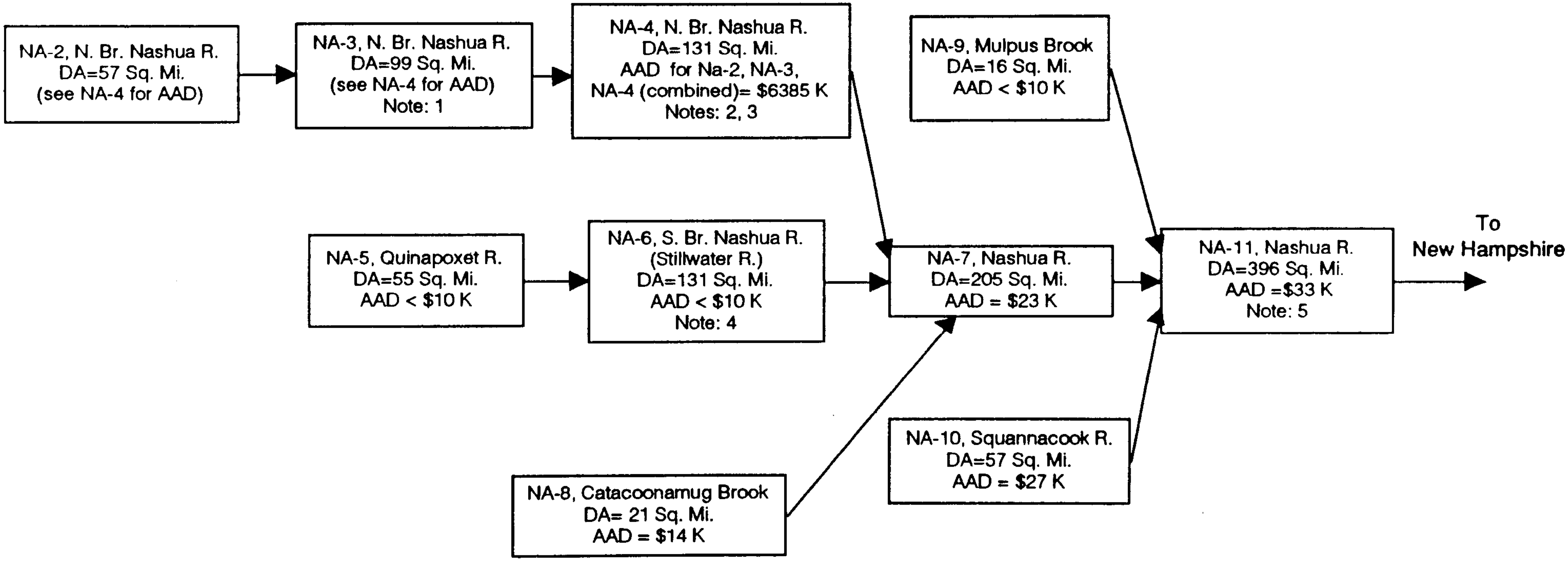
Figure 13

Nashua River Basin

Hydrologic Block Diagram

(Hydrologic Unit No. 01070004)

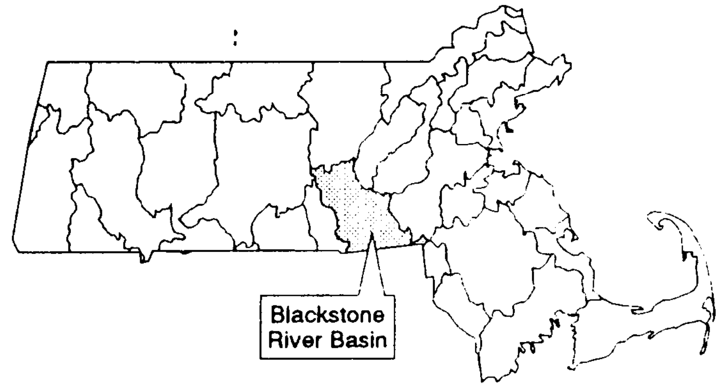


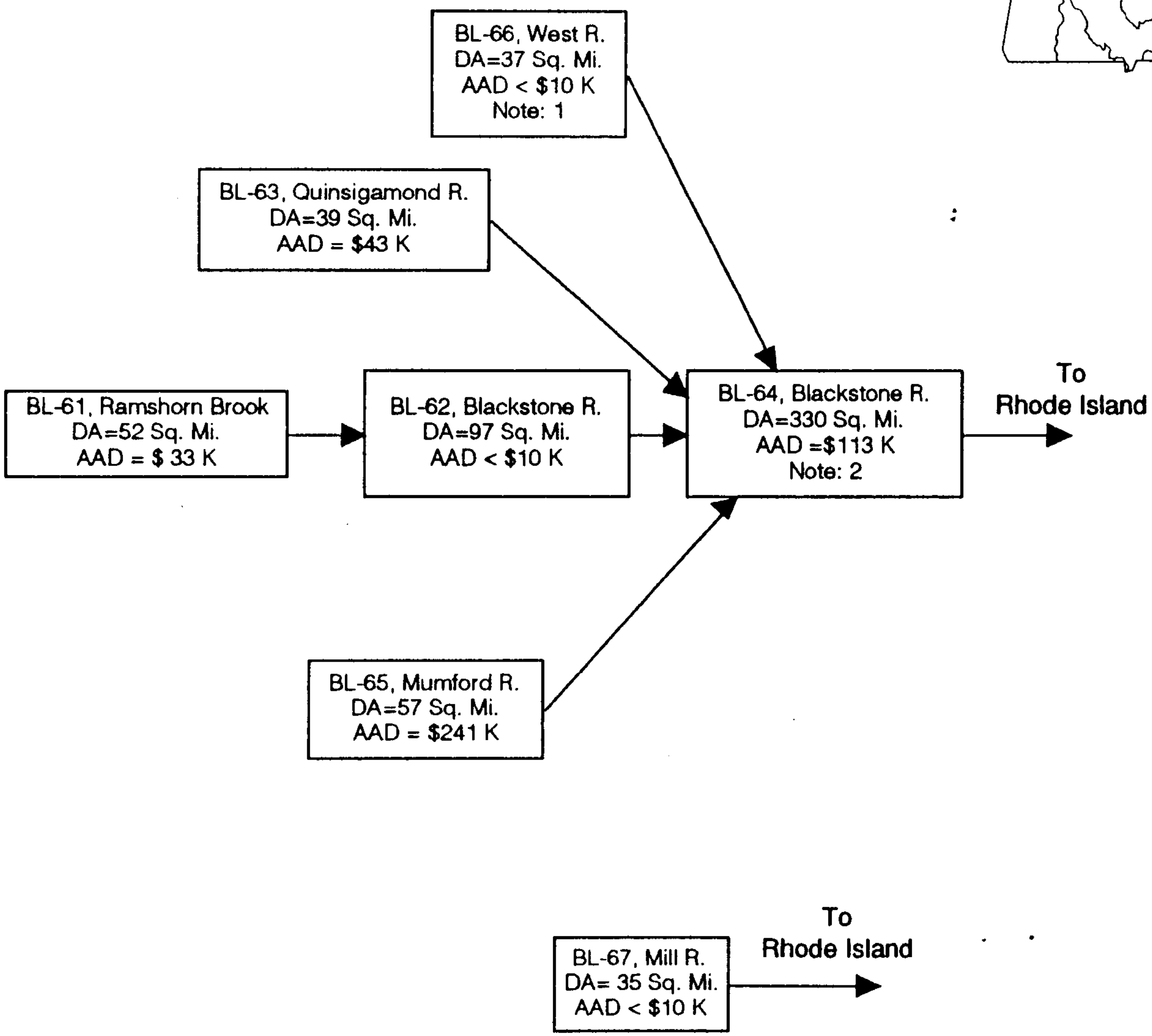


Notes:
1. USGS DCP, USGS Gage 01094400, N. Nashua River at Fitchburg, DA= 63 Sq. Mi.
2. USGS Gage 01094500, North Nashua River near Leominster, DA= 110 Sq. Mi. ,current NWS river forecast location.
3. Rebuilding of North Nashua River Local Protection Project (COE) reduced damages to the value shown.
4. Wachusett Reservoir (large MWRA water supply reservoir), DA= 108 Sq. Mi.
5. COE DCP & TM, USGS Gage 01096500, Nashua River at East Pepperell, DA= 435 Sq. Mi. (316 Sq. Mi. net after diversion), current NWS River forecast location.

Figure 14

Blackstone River Basin
Hydrologic Block Diagram
(Hydrologic Unit No. 01090003)

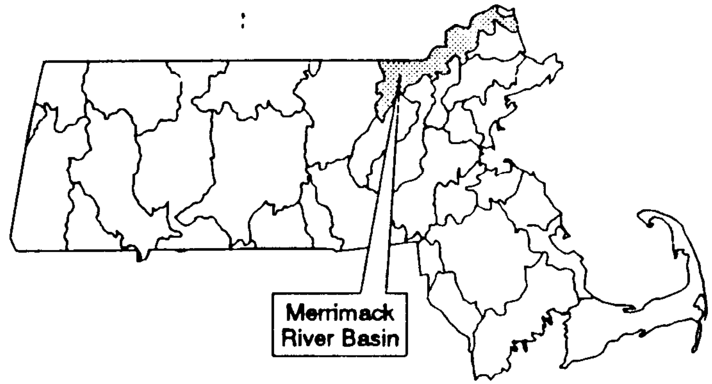


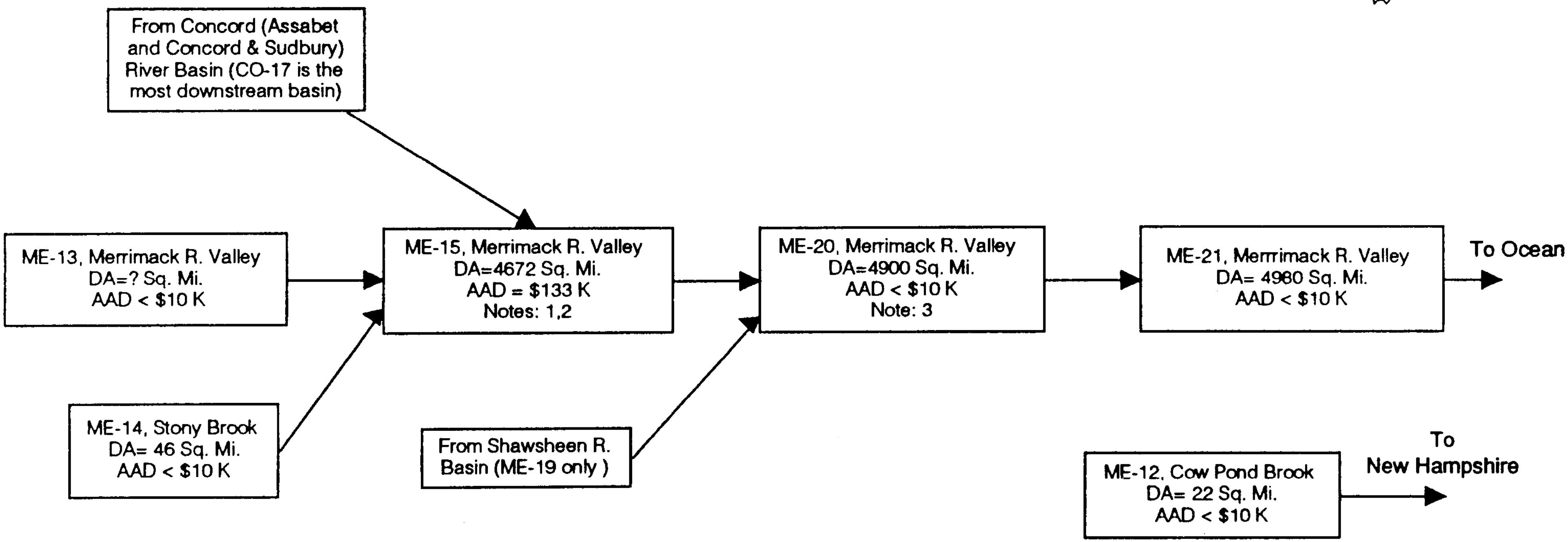


Notes:
1. West Hill Dam (COE Flood control reservoir), DA= 28 Sq. Mi.
2. COE DCP & TM, USGS Gage 01110500, Blackstone River at Northbridge, DA= 139 Sq. Mi. (upstream of BL-65 & BL-66), current NWS River forecast location.

Figure 15

Merrimack* River Basin
Hydrologic Block Diagram
(Hydrologic Unit No. 01070002)





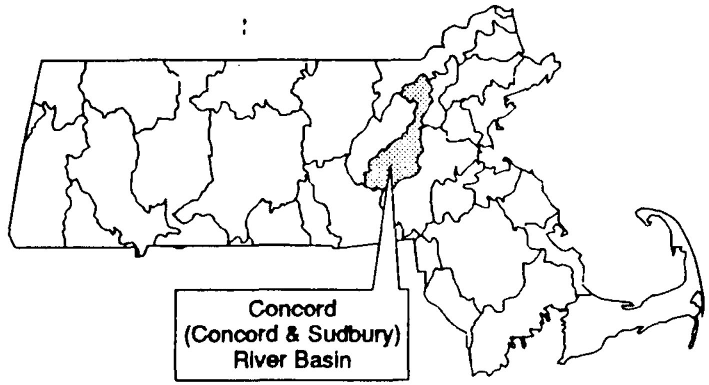
* Damages not estimated for the main stem

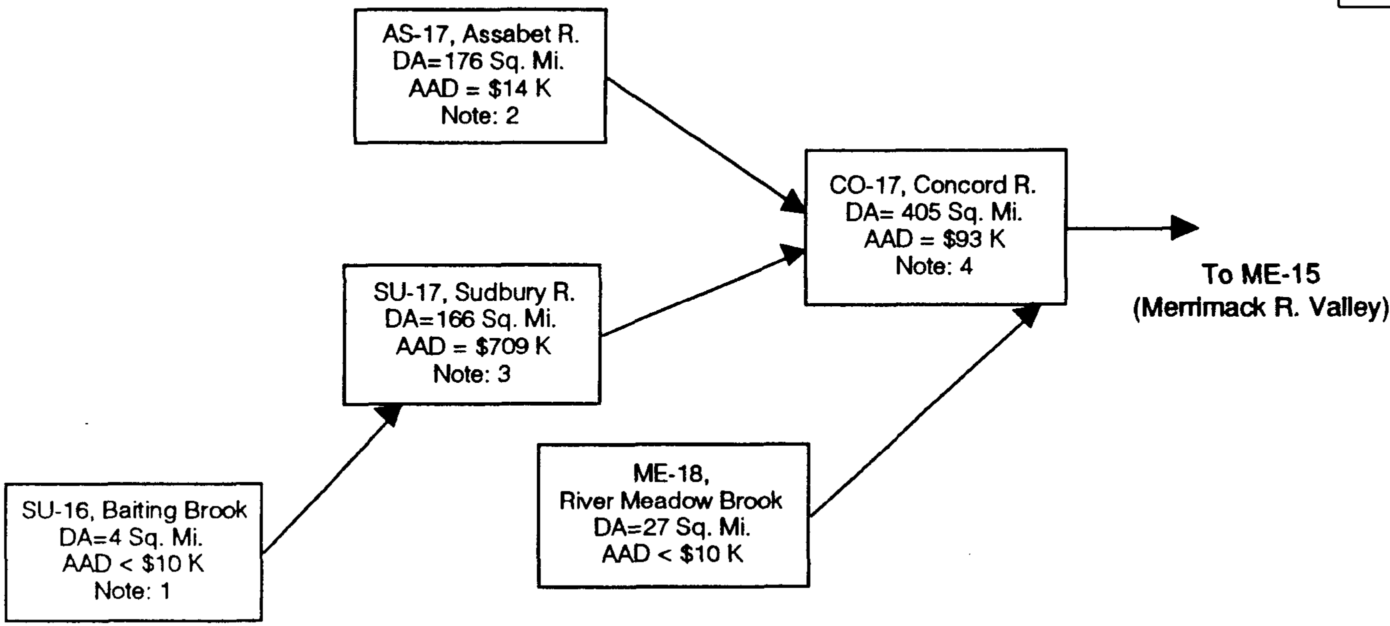
Notes:
1. COE DCP & TM, USGS Gage 01100000, Merrimack River below Concord River at Lowell, DA= 4635 Sq. Mi., current NWS River forecast location.
2. Current NWS River forecast location, Merrimack River at Lawrence, Power Co. Staff gage, DA=4461 Sq. Mi.
3. Current NWS River forecast location, Merrimack River at Haverhill, Staff gage, DA= 4900 Sq. Mi.

Figure 16

Concord River Basin

Concord (AS-17 only) and Concord & Sudbury (SU-16,17, CO-17, ME-18)
Hydrologic Block Diagram
(Hydrologic Unit No. 01070005)



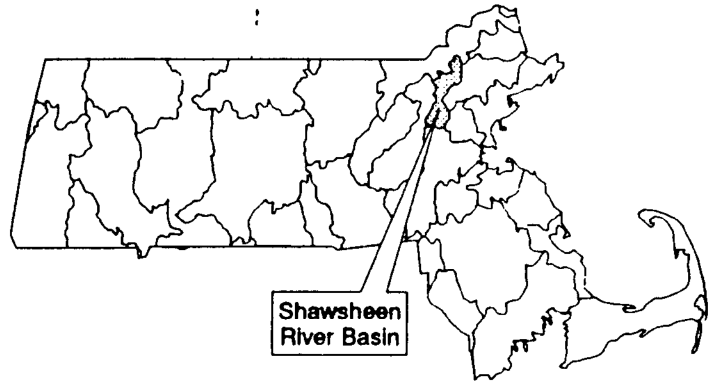


Notes:
1. SCS Baiting Brook Project (Fiske Floodwater Retarding Dam) reduces damages to the value shown.
2. Current NWS River forecast location, USGS Gage 01097000, Assabet R. at Maynard, DA= 116 Sq. Mi.
3. Saxonville Local Protection Project (COE) reduces damages to the value shown.
4. USGS Gage 01099500, Concord River below River Meadow Brook at Lowell, DA= 400 Sq. Mi. (net = 307 Sq. Mi. after diversion), Current NWS River forecast location.

Figure 17

Shawsheen River Basin

Hydrologic Block Diagram
(Hydrologic Unit No. 01070002)



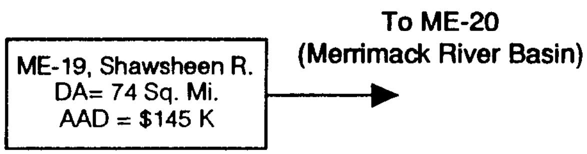
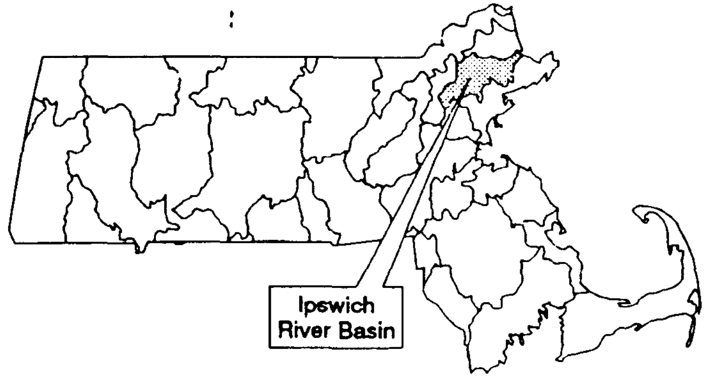


Figure 18

Ipswich River Basin

Hydrologic Block Diagram
(Hydrologic Unit No. 01090001)



IP-4, Ipswich River
DA= 156 Sq. Mi.
AAD = $235 K
Note: 1

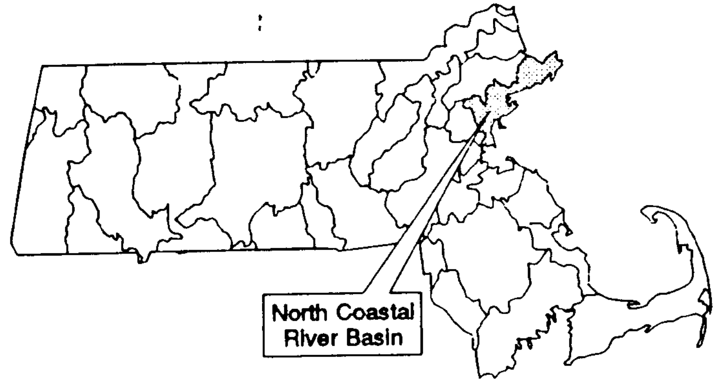
To Ocean

Notes: 1. USGS DCP, USGS Gage 01102000, Ipswich River near Ipswich, DA- 125 Sq. Mi.

Figure 19

North Coastal River Basin

Hydrologic Block Diagram
(Hydrologic Unit No. 01090001)



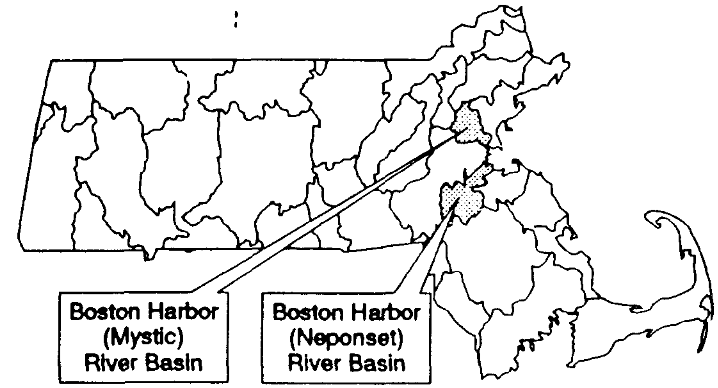
NS-7, Saugus R.
DA= 23 Sq. Mi.
AAD = $372 K

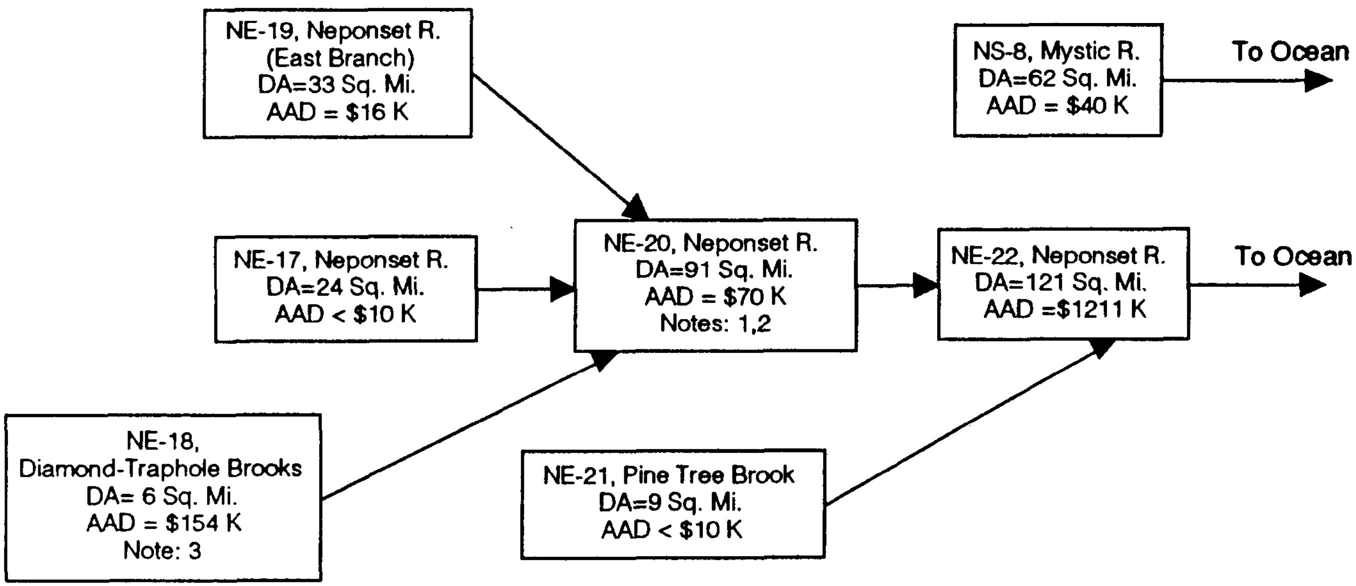
→ To Ocean

Figure 20

Boston Harbor River Basin

Mystic (NS- 8 only) and Neponset (NE-17 thru NE- 22)
Hydrologic Block Diagram
(Hydrologic Unit No. 01090001)

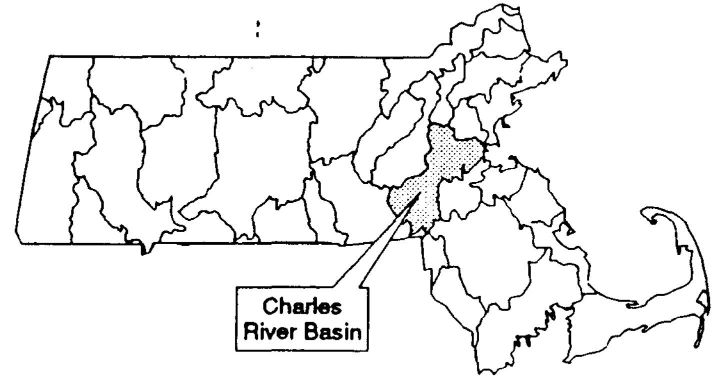


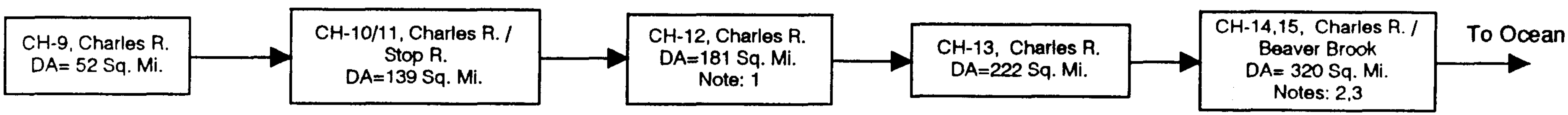


Notes: 1. USGS DCP, USGS Gage 01105000, Neponset River at Norwood, DA= 35 Sq. Mi., Current NWS River forecast location.
2. TM with precipitation only, at Norwood Airport.
3. SCS's Diamond Brook Watershed Project reduced damages to the value shown.

Figure 21

Charles River Basin
Hydrologic Block Diagram
(Hydrologic Unit No. 01090001)

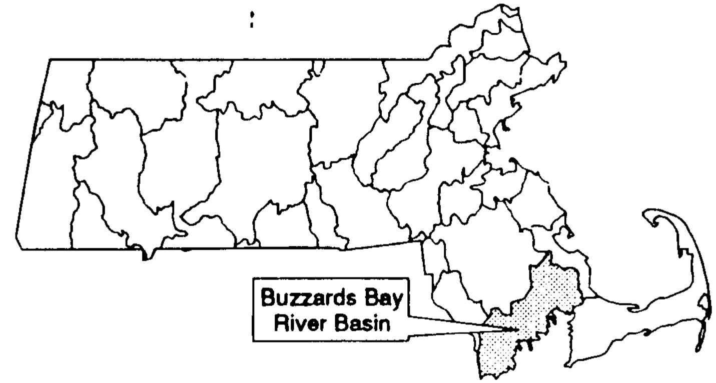




Notes:
1. USGS DCP & TM, USGS Gage 01103500, Charles River at Dover, DA= 183 Sq. Mi., current NWS River forecast location.
2. USGS DCP, USGS Gage 01104500, Charles River at Waltham, DA= 227 Sq. Mi.
3. The Charles River Natural Valley Storage Project (COE) had its most recent land acquisition in September 83.
   Also, the Charles River Dam (COE) was completed in May 78.
   These two projects reduced average annual damages (although uncalculated).

Figure 22

Buzzards Bay River Basin
Hydrologic Block Diagram
(Hydrologic Unit No. 01090002)



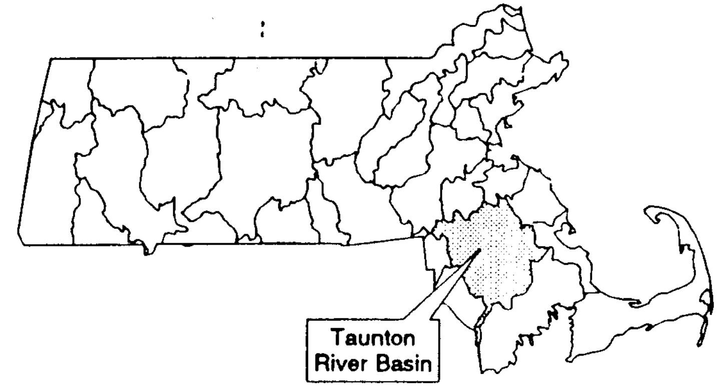
BB-42, Weweantic R.
DA= 45 Sq. Mi.
AAD = $182 K
→ To Ocean

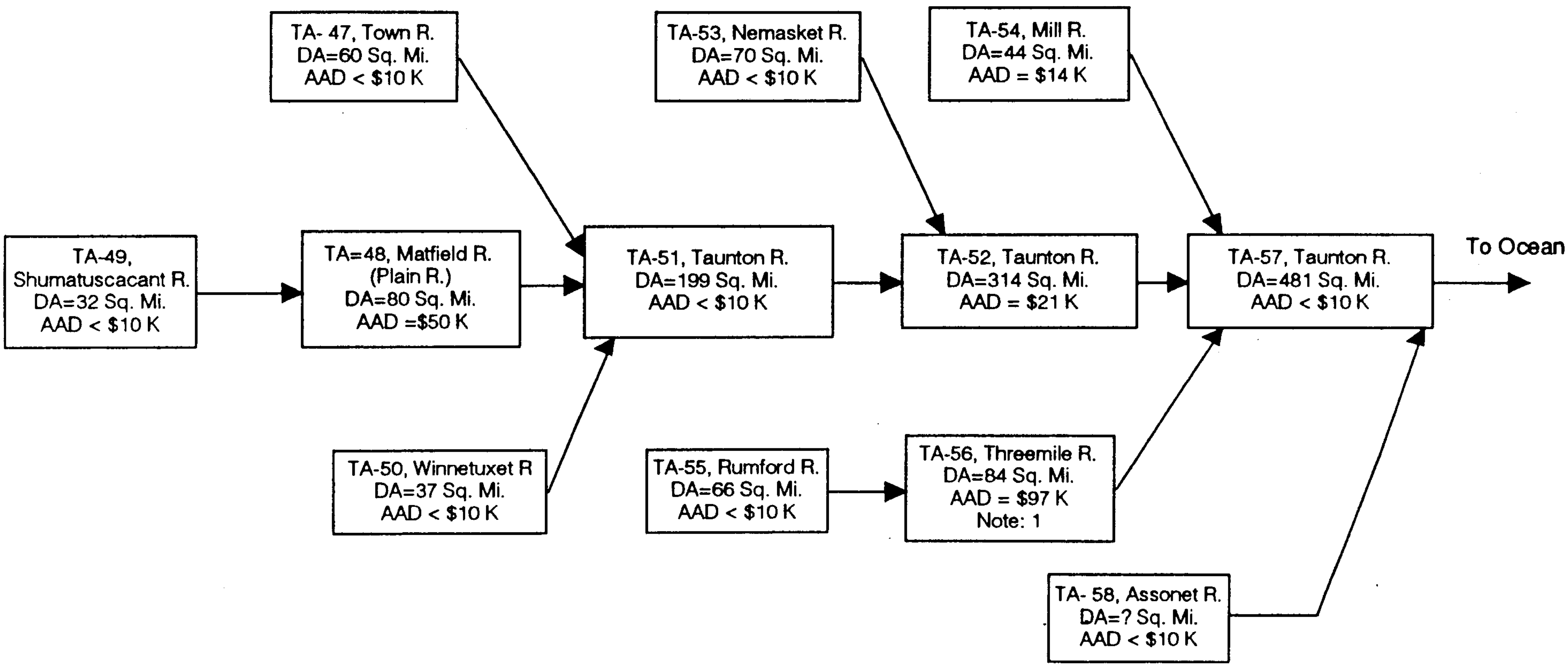
BB-45, Acushnet R.
DA=18 Sq. Mi.
AAD = $79 K
→ To Ocean

Figure 23

Taunton River Basin

Hydrologic Block Diagram
(Hydrologic Unit No. 01090004)



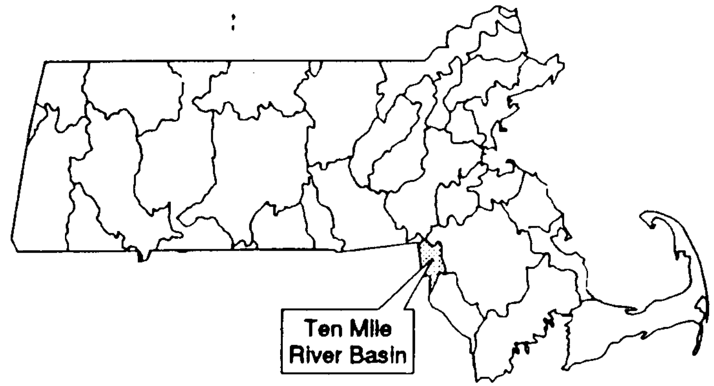


Notes: 1. USGS DCP, USGS Gage 01109000, Wading R. near Norton, DA= 43 Sq. Mi.

Figure 24

Ten Mile River Basin

Hydrologic Block Diagram
(Hydrologic Unit No. 01090004)



NB-60, Ten Mile R.
DA= 28 Sq. Mi.
AAD = $762 K

→ To Ocean

Figure 25

APPENDIX A

Typical ALERT Hardware Costs

A typical ALERT system for a small basin (up to 50 square miles) would consist of two (2) precipitation gages, a precipitation/stream flow combined gage, a smart repeater (a device that can store data until remotely queried), a base station computer with data collection software and all miscellaneous hardware. The following is a sample Software and Hardware cost estimate for a typical ALERT system provided by an ALERT system vendor. These costs include installation:

Type of Gage	Quantity	Unit Price	Total
Field Equipment:			
Precipitation Gage	2	$3,000	$6,000
Precipitation & Stream Flow Gage	1	$4,665	$4,665
Smart Repeater	1	$4,290	$4,290
Installation			$3,600
Base Station Hardware			
Antenna, Uni-Directional	1	$275	$275
Antenna Cable - 60 feet	1	$75	$75
Antenna Battery Backup	1	$65	$65
Lightning Arrester	1	$110	$110
Data Decoder	1	$2,600	$2,600
Backup Power Supply	1	$500	$500
IBM Personnel Computer	1	$1,695	$1,695
Math Co-processor Chip	1	$275	$275
Software			
Operating System	1	$750	$750
ALERT Data Collection and Interrogation Software	1	$3,000	$3,000
Subtotal			$27,900
Contingency (10%)			$2,790
Grand Total			$30,680

The estimation of initial hardware costs used in this study was based on the National Weather Services preliminary method of estimating the number of gages required for a basin. Other assumptions used included the need for only one combination precipitation/stream flow gage per basin, one repeater per basin and that the manual forecast tools would be provided by the NWS without cost to the end user.